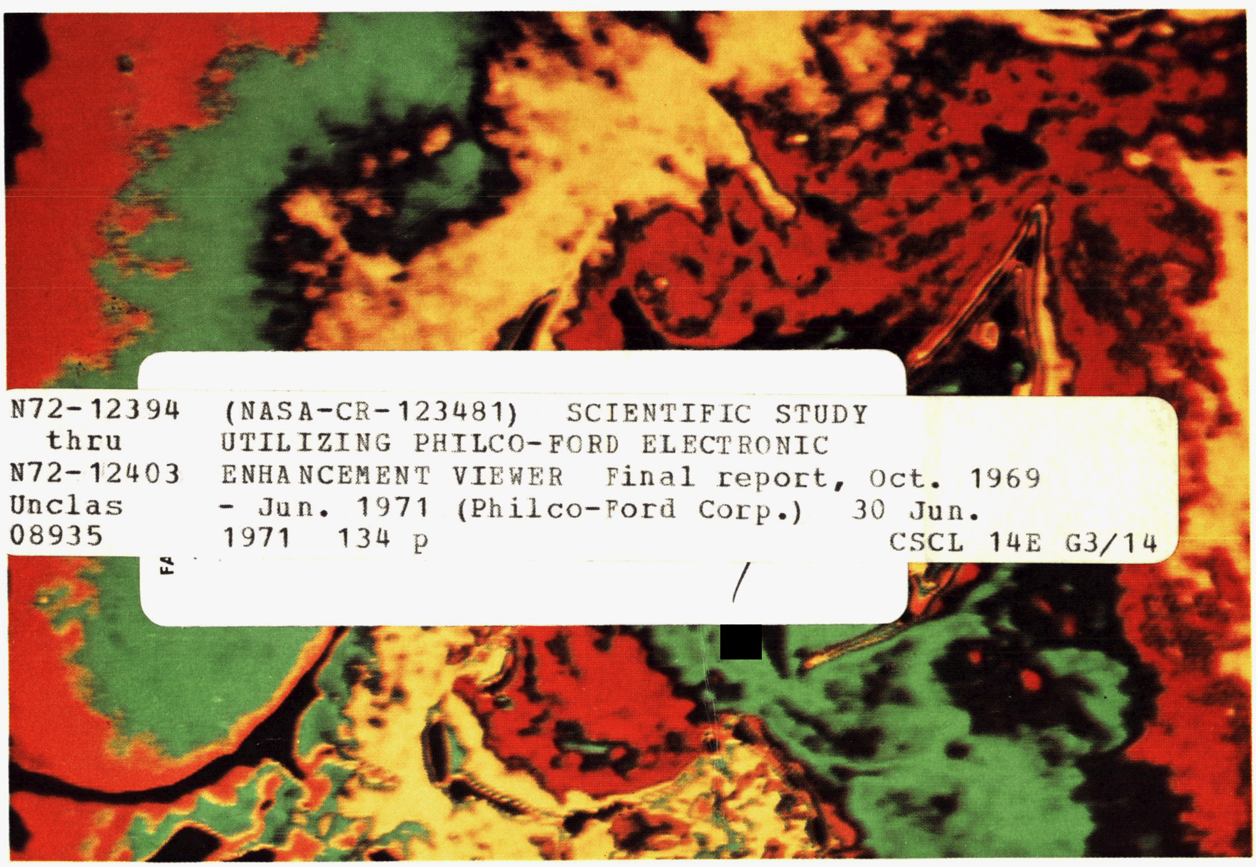
WDL-TR4498
71 Jun 30

10

SCIENTIFIC STUDY UTILIZING PHILCO-FORD ELECTRONIC ENHANCEMENT VIEWER

Prepared for
U.S. NAVAL OCEANOGRAPHIC OFFICE
Washington, D. C.
Contract No. N62306-70-C-0200



ENHANCED PHOTOGRAPH OF THE JAMAICA BAY, LONG ISLAND REGION

PHILCO Ford

Philco-Ford Corporation
Western Development Laboratories Division
Palo Alto, California 94303

NASA
Page 1-1

WDL Technical Report 4498
71 Jun 30

SCIENTIFIC STUDY UTILIZING PHILCO-FORD ELECTRONIC ENHANCEMENT VIEWER

Prepared for

U.S. NAVAL OCEANOGRAPHIC OFFICE
Washington, D.C.

Contract N62306-70-C-0200

PHILCO-FORD CORPORATION
Western Development Laboratories Division
Palo Alto, California 94303

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PRECEDING PAGE BLANK NOT FILMED

SECTION 1

INTRODUCTION

This report was prepared by the Philco-Ford Corporation, Western Development Laboratories Division, as a part of NAVOCEANO Contract N62306-70-C-0200, awarded 1 October 1969. This contract was initiated and completed at the request of the National Aeronautics and Space Administration (NASA).

The purpose of this contract was to provide the services of an electronic image enhancement viewer to various investigators in the NASA Earth Resources Survey Program. This viewer was used by a number of investigators in the program to enhance "high-flight" aerial and space photographs of geological, hydrological, oceanographic, and other earth science features for scientific study.

It is the objective of this final report to outline the use of and results obtained from the Philco-Ford enhancement viewer by these investigators. As a part of this report the relative merits of other techniques are analyzed and compared with the Philco-Ford system.

SECTION 2

VIDEO ENHANCEMENT - PRINCIPLES AND TECHNIQUES

2.1 VIDEO COLOR ENHANCEMENT PRINCIPLES

The information in a photographic image is made up of variations in density or variations in color that can be converted to density. The spatial arrangement of these variations forms areas, boundaries, or the outlines of objects. Many of the earth's resources and associated phenomena are recorded in photographs having very little density differentiation. The subtle changes in tone which deliniate ocean currents, differences in field crops, faint traces of geologic faulting, and the polluted air above a city are representative examples. However, photographic film is capable of recording these subjects, and even those with smaller density variations, which cannot be detected by any other method. If a photographic image is not enhanced, it is possible that the presence of valuable information may go undetected.

2.2 IMAGE ENHANCEMENT TECHNIQUES

The electronic image enhancement technique developed by Philco-Ford scans the small density variations in a transparency, greatly amplifies them, and converts them from analog form to a 16-step digital form. Contrasting false-colors are then arbitrarily assigned to each of the 16 steps or "slices" to clearly distinguish the successive density steps from one another. Enhancing and manipulation is accomplished electronically and the enhanced subject is then displayed on a TV monitor for study.

This process is also applicable to color transparencies. Color-separation filters are employed to separate the red, green, and blue bands. Each color record contains its associated spectral information and each is a subject for enhancement. Combinations of two or more spectral bands can be added to or subtracted from each other photographically to enhance desired, or suppress unwanted, information.

However, enhancing and manipulating the image in a photographic laboratory may require hours or days before the final result can be observed. The electronic image enhancement technique operates in real-time and the enhanced image can be altered or manipulated at any step to produce the desired image for study.

SECTION 3

VIDEO COLOR ENHANCEMENT VIEWER

3.1 PRINCIPLES OF OPERATION

The basic components of the electronic image enhancement viewer are shown in the block diagram, figure 3-1. A single black-and-white transparency of the subject (70 mm square) can be inserted either in the film gate of spectral gate 1 or spectral gate 2, or two identical transparencies may be processed simultaneously. A spot on a 1000-line flying-spot scanner is focused simultaneously on each transparency through a beamsplitter to sequentially scan each image. Photomultiplier tubes receive the light passing through each transparency, and the light is modulated in intensity according to the variation in image density, point by point. Each transparency image is thus converted into an electrical signal which, through the regular video circuits, will reappear on the black-and-white TV monitor tube as a 1000-line image of the input from the transparency(s).

To generate a color impression, the red-green color wheel rotates in front of the 14-inch TV monitor and the video signals are synchronized with the wheel to display a red image and a superimposed green image. This effect can also be generated in a single band by assigning different density signal levels to the different colors. The density variations in each input image are converted from an analog form to a 16-step digital form by quantizers. The 16 quantizer levels can be adjusted to fit the whole density range of the input image, or narrowed to form a 16-level staircase that can be moved through any part of the input image density range. Moreover, a portion of the red-green colors can be mixed to provide color differentiation for each step. This permits density slicing through the image with a false-color differentiation of the slices. This effect can be created separately for each input image. Two images can be added together, or subtracted electronically. Electronic edge differentiation is also provided, as is the capability of running one slice through the density range of either input image.

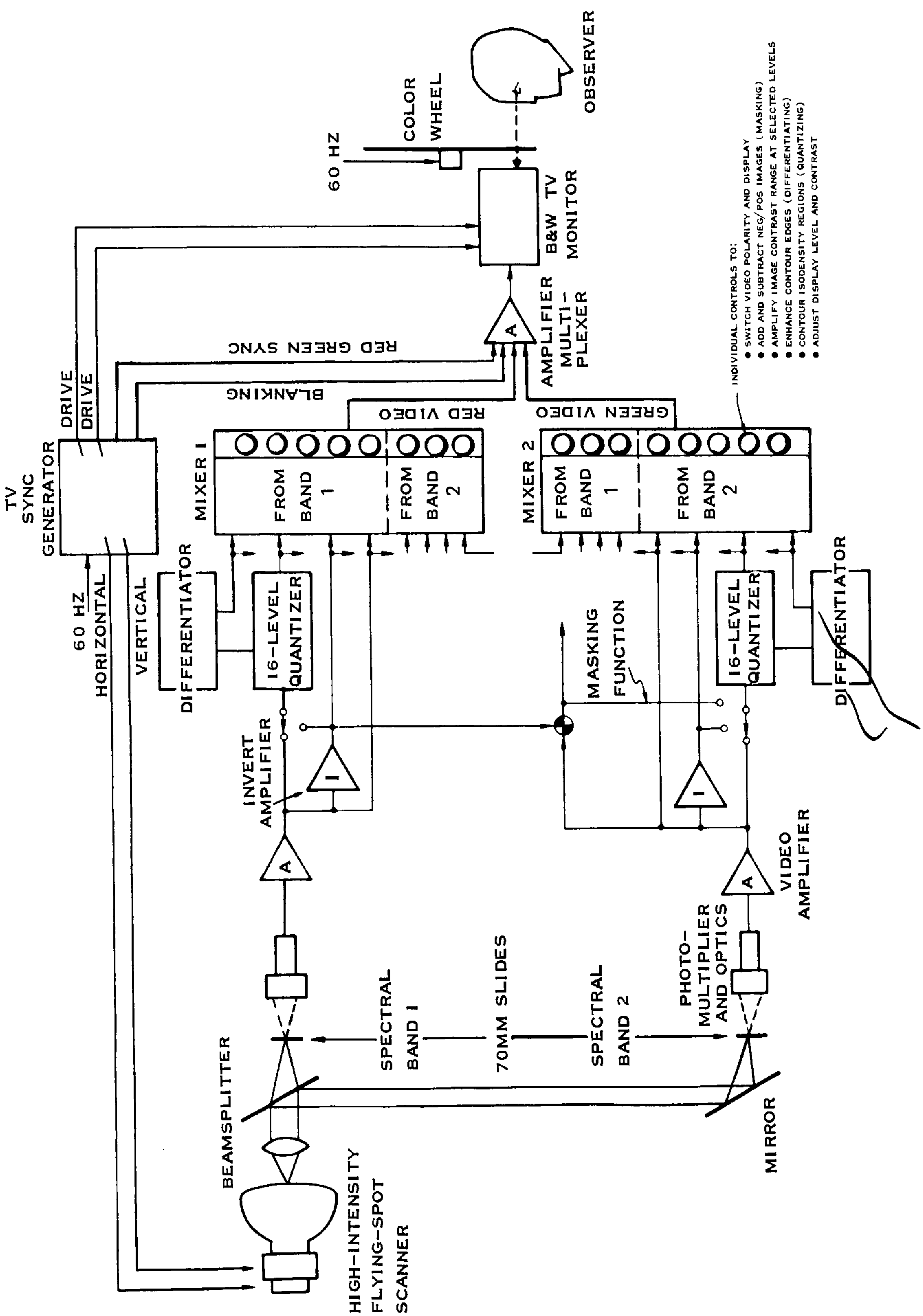


Figure 3-1 Block Diagram of Electronic Image Enhancement Viewer

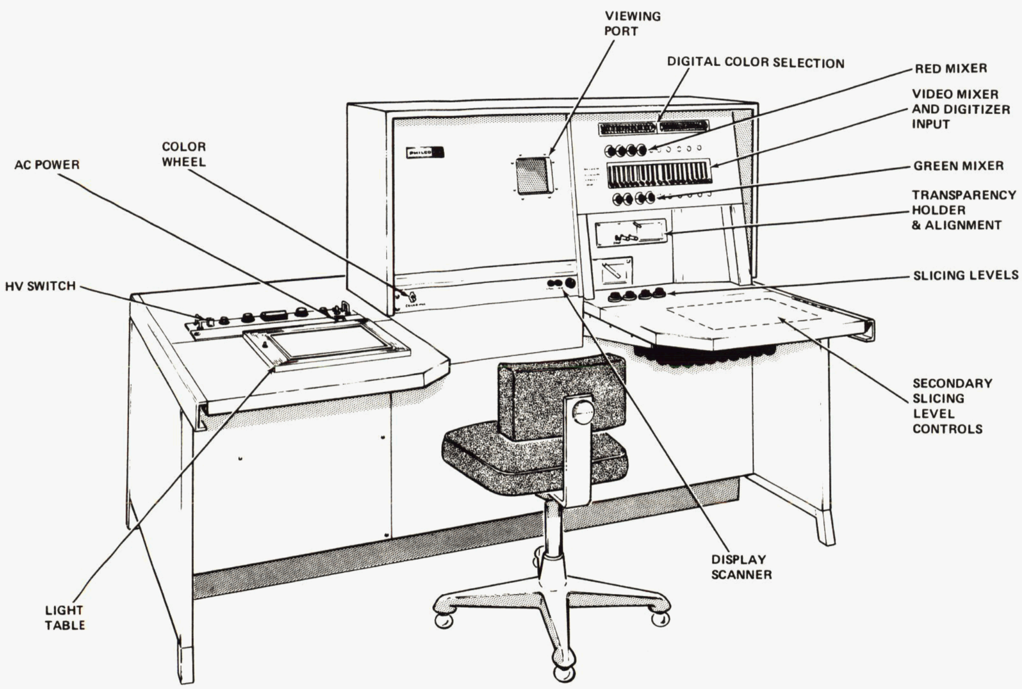
The 16-level quantizers accurately digitize a video signal having a bandwidth in excess of 10 MHz. Analog-to-digital conversion is done in parallel, using 16 integrated-circuit dual comparators for each spectral band.

Each comparator gives an output only when the video input signal is within a certain range of values. Each of the slicing levels is adjustable by individual controls located on the control console, figure 3-2. The film density or scene brightness bands defined by these levels are contiguous. The 16 output signals feed a resistor summing network to produce a stepwise-constant video waveform, which is then sent to the two mixers. The end result is a signal-processing circuit having a nonlinear transfer function that need not even be monotonic. The desired transfer function can be tailored for a specific task by changing the resistors in the summing network, which is accessible through the front-panel patchboard. By resistor selection, each of the 16 digitized brightness levels may be assigned individually to either of the display colors.

3.2 OPERATION

While the flexibility of control provides a wide range of enhancement effects, it was found that the user soon learns how to create the enhanced display that is best suited to his particular study or program. The following options are available for viewing each spectral band input:

- Straight video
- Image switching from positive to negative
- Single and multiple false-color density slicing with variable slice size and position within the image
- Combination of video in one part of the image with slicing in other areas
- Positive image in one color, negative image in another



(A) CONTROL PANEL LAYOUT

(B) CONTROL CONSOLE

Figure 3-2 Philco-Ford Image Enhancement Control Console

3.2.1 Video Mixer

The controls for the video mixer are located in the center of the upper control panel, figure 3-2. The mixer is divided into two sections: one for red and one for green. Each section has four inputs available: channel 1 and channel 2 unprocessed video from transparencies 1 and 2, and channel 1 and channel 2 digitized video for red and green, or a total of eight inputs. There is a level control and selector switch for each input. The four-position selector switch is located directly beneath its corresponding level control. The following table shows the four selector switch positions as they appear on the console and the position function.

SWITCH POSITION	FUNCTION
TEST RAMP	When the switch is in this position, an internally generated waveform is applied to the level control. This test waveform is used only with the digitizer input selector, and not with the mixer input selectors. This waveform is useful when changing the slicing levels or the colors assigned to each level.
INVERT	This position applies the normal unprocessed or digitized video signal to the corresponding input, but inverted in polarity.
NORMAL	This position applies the normal unprocessed or digitized video signal to the corresponding input.
OFF	The switch in this position grounds the corresponding input.

3.2.2 Digitizer

Each input channel has associated with it a 16-level quantizer. The input waveform, and hence the film density, is broken into 16 contiguous bands, and each band,

through the digital color selection matrix, is assigned a specific color. Therefore, specific colors presented on the display correspond to specific video levels. Normally, the colors are selected to make adjacent density levels easily discernable. The input selection, slicing levels, and color assigned to each level are all under operator control.

The input to the digitizer is controlled by the switch labeled CH 1 DIGITIZER INPUT or CH 2 DIGITIZER INPUT. When the switch is in the OFF position, no input is applied to the digitizer and no digitized information can be displayed, even though the digitized output selector switches in the video mixer are actuated.

There are two sets of controls for adjusting all 16 slicing levels. The primary set, used in the normal operation of the viewer, is located on the rear top surface of the right-hand table. These controls, labeled SLICING LEVELS - WIDTH and POSITION, determine the total width and position of the 16 slicing levels. The effect of these controls is best seen when the digitizer input switches are set in the TEST RAMP position.

The secondary sets of slicing level controls are located under the right-hand table and are accessible by raising the table top. These controls determine the slicing levels for each of the 16 quantizers. Normally, these controls are set to simulate a particular function (linear or logarithmic) using the test ramp input, and then are left alone during the remainder of the run. For proper operation of the viewer, it is imperative that these controls be set so each corresponding level is higher than the level preceding it. The ordering of the levels may be checked by observing the TEST RAMP and slightly perturbing each slicing level in order.

The color assigned to each digitizer output is selected by setting the potentiometers in the digital color selection matrix, and may be checked by observing the TEST RAMP. The individual potentiometers in the digital color selection matrix determine the level of the red video and green video for each level. The colors may be changed by observing the TEST RAMP, making sure that both the red and green digitizer outputs are set and the corresponding video mixer potentiometers are at

approximately equal settings (usually wide open). The red and green potentiometers of the digital color selection matrix are then adjusted for the level under consideration. The individual colors selected are not changed for the duration of the run. The overall color balance of all 16 levels can be adjusted by the level controls at the video mixer.

3.2.3 Scanner and Display Controls

The DISPLAY CONTRAST and DISPLAY INTENSITY controls are shown in figure 3-2A (DISPLAY SCANNER) and are identical to those found on a commercial TV set. The DISPLAY INTENSITY control should be adjusted to the point where the display disappears when all mixer switches are in the OFF position.

The SCANNER INTENSITY controls the brightness of the scanning beam and can be adjusted to compensate for extremely light or extremely dense slides. Normally, the control is in about the middle of its range. For very small slides, the intensity is somewhat decreased. Too high an intensity, as evidenced by clipping in the unprocessed video (highlights washed out) or by an increase in displayed picture size is undesirable. This will produce an excessive photomultipler current, possible phosphor burn, and a loss in resolution due to beam defocusing.

SECTION 4

USERS' RESULTS AND CONCLUSIONS

SECTION 4.1

ADDITIVE COLOR IMAGE ENHANCEMENT
TECHNIQUES AND EQUIPMENT

Jerry D. Lent
Research Specialist
Department of Geography
Forestry Remote Sensing Laboratory
University of California
Berkeley, California

SECTION 4.1

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

Section 4.1 is an extract from the report "An Evaluation of Earth Resources Using Apollo 9 Photography" available from the University of California, Department of Geography, Forestry Remote Sensing Laboratory (FRSL), Berkeley, California.

Mr. J. D. Lent who participated in the evaluation of the photographs, is currently a Research Specialist at the University of California, Forestry Remote Sensing Laboratory, Berkeley, California.

In this study Mr. Lent used the Philco-Ford electronic video enhancement viewer to compare the results with other available image enhancement techniques. The equipment and enhancement methods are discussed and recommendations proposed for future photographic enhancement.

2.0 PRIMARY STUDY OBJECTIVE

The primary objective of this study was to investigate and describe some of the enhancement techniques and equipment used in the evaluation of the S065 photography.* The potential usefulness of such techniques to inventory the earth's resources will be indicated only in a general way.

The purpose of any form of image enhancement usually is two-fold: First, to increase the total amount of information that is derivable from the raw data; and secondly, to facilitate the data extraction process, as shown in figure 4.1-1.

When additive color image enhancement techniques are employed, these objectives are usually realized by highlighting subleties in image tones. Such enhancements can be accomplished by either optical or electronic means.

*Photographs taken by Apollo 9 astronauts in 69 March and labeled scientific experiment No. S065.

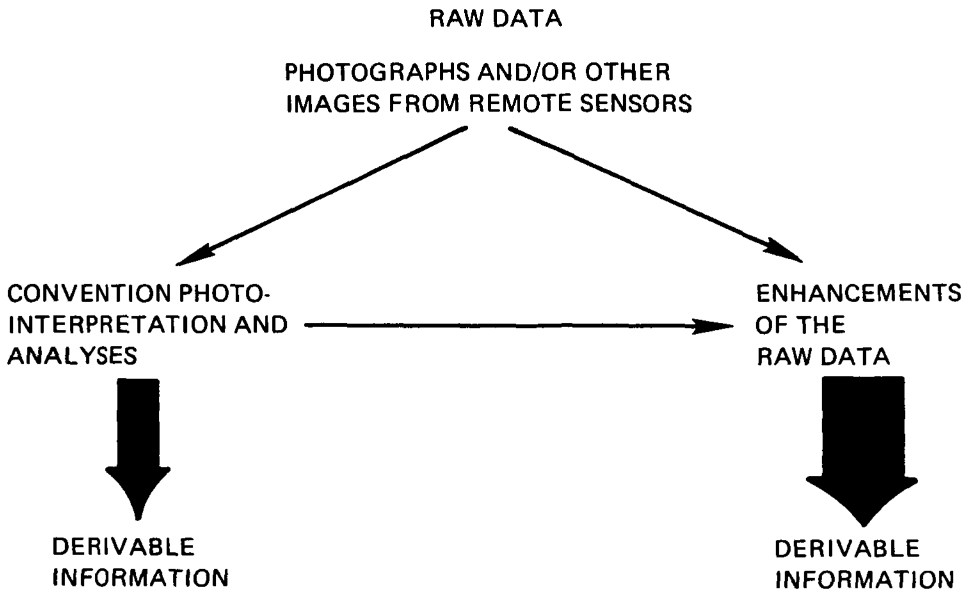


Figure 4.1-1 Data Extraction Process

2.1 Basic Principles of the Additive Color Process

Possibilities inherent in some of the new adaptations of the additive color process are best appreciated if we first examine an elementary principle that is illustrated in combining two colors. If two colored light beams, one red and the other green, are projected on a screen in such a way that only a small portion of each was allowed to overlap the other, the result of this particular additive color combination is yellow. On such a composite image, sharp color differences and clearly defined boundaries differentiate three types of areas: (1) those in which only red light is present (2) those in which only green light is present, and (3) those in which both red and green are present, producing the additive color, yellow. Many other color combinations are possible, and the technique need not be limited merely to the use of two light beams. It would be highly beneficial for certain experiments to use three and possibly four color combinations. The most common form of additive color enhancement employs an optical combiner and involves the use of a series of multiband images (transparencies) all showing the same scene. Each image is projected by means of a light beam which has a particular hue because a colored

filter is placed in its path. The individual color images are then superimposed on a suitable viewing screen to form a single color image. The colors exhibited on this composite image are a function of (1) image densities of the multiband transparencies, and (2) the color values of the filters through which the transparencies are projected.

2.2 Advantages and Limitations

There are some limitations as well as advantages associated with the use of additive color enhancement for those who seek to inventory earth resources from multiband space photography. These limitations of additive color enhancement techniques include: (1) limitations in the extent to which enhancements can be accomplished, (2) the need for special equipment with which to perform the enhancements, and (3) the requirement for special interpreter training.

Enhancements are usually performed to highlight differences between multiband images. The mere addition of various colors (when projecting and superimposing images that were obtained under identical conditions of time, exposure and film-filter selection) does not invariably result in an improved data extraction capability. If there are no density differences between the multiple images that are to be studied, then there is not much point in attempting image enhancement. At the other extreme, if there appear to be very large density differences between the multiple images, there may be no need for enhancement because of the ease with which such differences can be discerned even on unenhanced imagery. Thus, the condition under which enhancement can prove most useful usually occurs when the data sources have relatively subtle density differences that may go undetected under visual grey-level discrimination. Optical and electronic enhancements can be used to reveal these subtle density differences.

The image analyst must become familiar with certain special kinds of equipment in order to use color enhancement techniques successfully. Some of this equipment can be extremely expensive and consequently unavailable to many of the experimenters who need it most. Furthermore, most of the current elaborate color enhancement systems are prototypes of systems that will undoubtedly undergo refinements

requiring further familiarization before they can be readily used by a skilled image analyst.

Finally, the image analyst will need to be trained in the skills of interpreting additive color enhanced images that often exhibit "unconventional" distortion, resolution and color display characteristics.

A few of the most important advantages of the additive color enhancement techniques are as follows:

- The most obvious advantage to be gained from the use of color enhancement technique is the ability of the image analyst to combine the information (either electronically or optically) from several multiband images into one single frame for interpretation purposes. Mentally integrating the multiband tone signatures of various kinds of objects can be a difficult, if not impossible, task unless the images are themselves integrated and color coded as in the additive color process.

- Another very important aspect of the color enhancement technique is the exploitation of sequential differences which might exist between data acquisition missions flying the same film-filter combinations. Any differences in the data could most likely be attributed to changes in the feature condition or state from a previous flight. This assumes, of course, that the remaining factors affecting the recorded tone signatures were sufficiently known for standardization.

Some mention should be made of the analysis potential of electronically controlled additive color enhancement systems. Such systems, while considerably more complex and expensive to develop, afford the image analyst greater flexibility in interpreting the data. Very subtle grey-level differences can be "sliced" and electronically "expanded"; then digital codes can be ascribed to them for subsequent analysis. Color enhancement can be accomplished by electronically assigning different color codes to specific input densities. Similarly, the information recorded on the individual layers of the color film emulsion can also be directly

encoded and redisplayed with different colors, if necessary, for greater interpretability. Consequently, greater flexibility of color display may be possible with electronic enhancement systems than with photo-optical ones.

2.3 Image Enhancement Systems Which Employ Color in Their Displays

2.3.1 Forestry Remote Sensing Laboratory (FRSL) Optical Color Combiner

An unsophisticated, but effective color combiner, used in one form or another by several research groups, is exemplified by the one used at the NASA-USDA Forestry Remote Sensing Laboratory, University of California, Berkeley. Figure 4.1-2 diagrams the technique employed with that equipment in optically combining multiband images and projecting them through color filters to produce color enhanced scenes.

The advantages of this optical system are: (1) its ease of construction and use (the equipment is inexpensive and readily obtainable, and the enhancements are readily performed), (2) the data can be directly interpreted from the screen, and (3) there is a large selection of color filters, and thus a large number of color combinations available for experimentation.

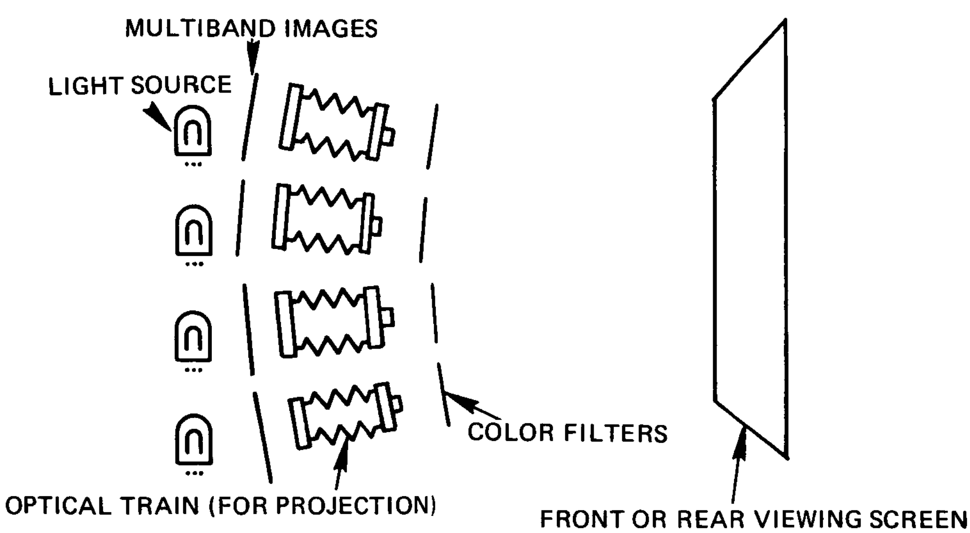


Figure 4.1-2 Optical Color Combiner

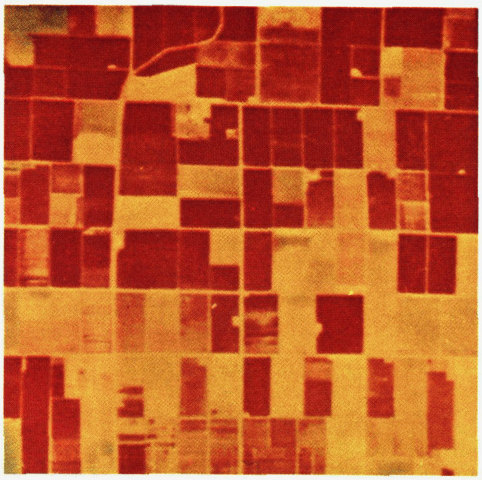
Limitations are mainly related to the deficiencies encountered in attempting to use conventional light sources for more flexibility of color combinations (since some of the color filters are exceedingly dense for some illuminants). There is also the problem of adequate registration of images for color enhancement; slight differences in geometry between images can cause density combinations that are confusing to interpret. In addition, one problem can result from the use of uncalibrated data of variable quality, and another when images from two separate photographic missions are enhanced. The densities to be enhanced must have some quantitative relationship to the features they represent; hence, changes in the time of photography, sun angle, film type, or even processing procedure can cause shifts which alter this relationship.

One example of the output from the FRSL optical color combiner is shown in figure 4.1-3A, where it can be compared with outputs from two other types of systems for enhancement purposes.

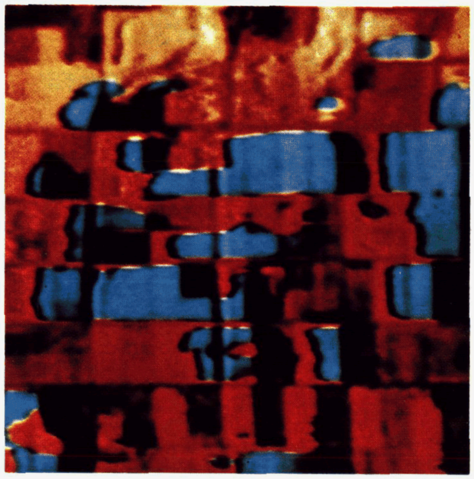
2.3.2 University of Kansas Electronic Processing System (IDECS)

An electronic image enhancement and correlation system has been designed and built by personnel at the Center for Research in Engineering Science Laboratories (CRES), University of Kansas. This electronic image discrimination, enhancement, combination, and sampling (IDECS) system has been designed as a flexible research tool in defining application techniques for multi-image interpretation.

With the IDECS system, image enhancements can be accomplished either among monochromatic combinations of multiple images (for example, grey level enhancements without the production of color composites) or by additive color combinations of them. Added to this advantage is the ability of the operator to "level select" for tone or brightness range on one or more images for the purpose of highlighting or encoding spectral densities. Isodensity enhancement can be performed and directly analyzed by online computer software. Input images (up to 3 by 4 inches in size) to be interpreted can be from different imaging sensors, of somewhat different geometry, since "reasonable" linear distortions between images can be corrected electronically. The output display interpretation and recording is best performed



(A) FRSL OPTICAL COLOR COMBINER. THE OPTICAL SYSTEM, NATURALLY, HAS THE BEST RESOLUTION.



(B) IDECS ELECTRONIC COLOR DISPLAY AND ANALYSIS SYSTEM. THIS SYSTEM HAS THE POOREST RESOLUTION.

(C) PHILCO-FORD CONSOLE VIEWER HAS A FINER RESOLVING SCANNER AND, CONSEQUENTLY HAS THE NEXT BEST RESOLUTION CHARACTERISTICS.

NOTE: THE THREE EXAMPLES SHOWN ABOVE ARE ENHANCEMENTS OF THE SAME TEST SITE. EACH SYSTEM HAS ADVANTAGES AND DISADVANTAGES. SEE SECTION 4.2 FOR A DETAILED EVALUATION OF THE THREE SYSTEMS.

Figure 4.1-3 Examples of Color Enhancements Obtained from the FRSL, IDECS, and Philco-Ford Systems

directly from the viewing screens, but documentation is possible by photographing the viewing screens with conventional color films (Kodacolor X or Kodachrome II).

Some of the features of IDECS described above provide interpretation flexibility that optical systems cannot duplicate. For problems where spatial resolution may be very important, an optical system usually is superior to IDECS. For problems where large amounts of multiband imagery must be analyzed quickly, the IDECS system is far more efficient than current photo-optical systems. With appropriate hardware implementation, far more images can be effectively combined by this system than by photo-optical systems. IDECS is currently designed to accommodate six images, but this is not a technical limitation, as the number of images, which eventually might be simultaneously analyzed by such a system, can be increased.

An example of the output from the IDECS console viewer is shown in figure 4.1-3B, where it can be compared with other enhancements from related systems. For a more detailed report of the IDECS system see section 4.2.

2.3.3 Philco-Ford Image-Tone Enhancement Systems

The Philco-Ford electronic video enhancement viewer is an example of a system which incorporates both photo-optical and electronic capabilities for enhancement purposes. This system is capable of combining two multiband images which are illuminated by a single source of light for projection and scanning. Beamsplitting optics eliminate any possibility of variance in the relative intensity between two or more illumination sources. This feature also reduces the number of flying-spot scanners that the system requires. The scanner employed in the Philco-Ford viewer has a resolution of approximately 1000 lines, while the current IDECS system employs scanners which can resolve only about 500 lines. This is comparable to commercial television displays.

A special color wheel is employed in this system, which results in the additive color mixing of red and green hues. Sixteen levels of density can be referenced within each channel and "digitized" for subsequent quantification. The "level select"

feature is nominally linear and, like the IDECS system, can be expanded and contracted. Each density level can also be modified should the image analyst prefer to weigh its importance in the display. An example of the output from this console viewer is shown in figure 4.1-3C, which can be compared with the other two previously described systems.

Since the Philco-Ford system presently accommodates only two spectral bands, mention should be made as to how this capability can be improved to accommodate four bands. Let us assume that as many as 6 or 8 bands of black-and-white photography have been obtained simultaneously of the area in which we wish to make multiband image enhancements using the Philco-Ford viewer. From a densitometric study of the tonal characteristics of each of these simultaneous exposures, four bands were selected on each exposure where unique tone values appear for certain earth resource features.

For image enhancement purposes all of the remaining negatives were discarded because the tone values for objects that are to be identified differ the least from tone values of other negatives in the series. The remaining four are paired off to provide two pairs of negatives. Obviously, if the two negatives of a pair exhibited exactly the same tonal characteristics, there would be no advantage from using two instead of merely one. Since it is, therefore, the differences in tone between the two members of a pair that most likely will lead to the correct identification of objects, the negative transparency of one member of each pair is superimposed on a positive transparency that has been made from the other member of the pair. When the two transparencies are in proper register and light is directed through them, the bright images of one transparency are exactly offset by the dark images of the other transparency, except for objects having differences in reflectance in the two spectral bands that were used in obtaining the two spectrozonal photographs.

Exploiting only these differences, a composite black-and-white negative is made from each of the two matched pairs. The two resulting composite negatives thus highlight the differences in light reflectance in a total of four separate zones. These two composite negatives (or positive transparencies made from them) could then be used in the Philco-Ford viewer.

While a similar process could be used in either the FRSL optical combiner or the IDECS system, the need is not as great since they can accept a larger number of original multiband transparencies as direct inputs to the system.

2.3.4 Other Systems

A few other systems warrant mention here because of their unique capabilities to produce image enhancements. The first of these systems is the Long Island University multispectral camera viewer.

Another type of multiband image enhancement system is exemplified by equipment which has been designed by Technical Operations, Inc., of Burlington, Mass. This is an optical enhancement system which enables multiple color image retrieval from a single emulsion plane. Through a novel "camera" design which incorporates specially ground gratings ("spatial carriers") of extremely fine resolution, a number of multiband exposures can be placed on the same emulsion plane and later retrieved and colors assigned for display purposes.

The problem of registration is eliminated with the Technical Operations system. The camera can be used either to record single images of many different scenes or, for multiband work, can be filtered with the gratings in such a way as to record multiple images of a single scene, each in a different wavelength band.

There are many scientists experimenting with devices and techniques that closely resemble those described. RCA, General Electric, and Hycon, for instance, are experimenting with very sophisticated color enhancement systems that are being used for a number of varied applications. A few "hybrid" optical systems can be found in various research laboratories similar to the FRSL apparatus. Some employ the same image format (3 1/4 by 4 inches) while others employ 35 mm transparencies. At the present time all of these devices or systems can be regarded basically as research tools with which the image analyst can experiment. The need for electronic systems that automate the enhancement procedure and provide online computing capability will probably only help the interpreter to keep pace with the large volumes of imagery that will require analysis.

2.4 Practical Applications

It should be apparent that additive color enhancement techniques are generally still in the research phases of development in terms of practical applications. However, some mention should be made about their potentially beneficial uses for the resource planner. The need for further research is manifested by a desire to quantify the techniques to the extent that predictable, consistent results can be obtained from future experiments designed to inventory earth resources using multiband imagery from space or high-flying aircraft.

Once the following technical problems have been resolved, then practical and operational use of data reduction and enhancement techniques will become routine.

- Determination of which wavelength bands are most useful for each particular terrain feature of interest. Different and varied recommendations will be presented as to resource types

- Determination of color combinations and enhancements that will yield maximum information to satisfy the objectives of the experiment

Efforts to provide solutions to problems in the above three areas will continue to be made at a number of institutions, including the University of California, Forestry Remote Sensing Laboratory at Berkeley. Processors of remote sensing data acquired for agricultural areas should be able to identify crops and estimate yields by enhanced tones or hues. Such capabilities would materially assist the continued development of a strong agriculture program policy. Enhanced imagery can assist foresters and other wildland managers who have some rather complex multiple uses of resources to keep in mind. Hopefully, enhanced imagery soon can be used operationally in timber typing, detecting stand infestations, locating recreation sites (or more importantly, sites not suitable for recreation or specific purposes), delineating soil boundaries, and making management decisions such as brush conversion and planting. In fact, there is a strong possibility that all conventional uses of photography, including its interpretation for resources management purposes, can be facilitated in the near future through the use of proper image enhancement techniques.

SECTION 4.2

A COMPARISON OF ENHANCEMENT VIEWERS

Dr. John E. Estes
Associate Professor of Geography
University of California
Santa Barbara, California

SECTION 4.2

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION 4.2

LIST OF TABLES

1.0 INTRODUCTION

This study was undertaken to achieve a quantitative evaluation of electronic multi-image processors and was performed by Dr. John E. Estes, Leslie W. Senger in conjunction with G. W. Dalke, Dr. D. S. Simonette, et al., of the University of Kansas, Lawrence, Kansas.

Dr. John E. Estes, Associate Professor of Geography at the University of California, Santa Barbara, was the key investigator. Dr. Simonett, who directed the project, is presently the Director of the Department of Geography at the University of Sidney, Australia. Mr. Senger worked in conjunction with Dr. Estes and is associated with the Forestry Remote Sensing Laboratory (FRSL) at the University of California, Berkeley, California. Mr. Dalke is with the Center for Research in Engineering Science (CRES) at the University of Kansas, Lawrence, Kansas.

2.0 SCOPE OF THE STUDY

This study evaluates the capabilities of electronic processors such as the University of Kansas electronic multiimage processor (IDECS), the Philco-Ford viewer, the Forestry Remote Sensing Laboratory optical combiner (FRSL), the CIRID (a combined interpretation of color and infrared Ektachrome), and also imagery obtained by photographic systems, such as Ektachrome, infrared Ektachrome, or Pan 25A photography.

In order to evaluate the enhancement methods, statistical information was gained from an aggregate sample of 45 users. The time and accuracy information was used as raw data for a specifically designed computer program. Rankings of the imagery methods were made in terms of correct responses, fewest commission errors, least time, and lowest total by individual categories.

The results can be interpreted in a variety of ways. The results from each major experimental imagery category were summarized and an overall ranking summary was also provided. The conclusions are left to the reader.

3.0 SCOPE OF EVALUATION

A comparative test sequence was performed to relate the interpretability of particular images obtained with the University of Kansas electronic multiimage processor, image discrimination enhancement combination and sampling system (IDECS), to that of comparable images produced by other combiners of multispectral images and by images originally produced on both filtered panchromatic and color films. For each technique or device used, an enhanced/combined image was selected for each category at each test site and comparisons were made of their interpretability in terms of errors of omission[1] and commission, correct identification, and time for interpretation. The interpretation tests were designed to (1) obtain statistically valid measures of interpreter performance when studying the different kinds of imagery, (2) measure this performance in terms of both time required and accuracy achieved, and (3) measure performance as a function of the background of training and experience of the photo interpreter.

Testing the various systems with the various types of interpreter and various categories at each of the test areas required a large number of interpretations. When each system could only be represented by a single image for a given test site, color films and filtered panchromatic images were not severely limited, but false color combination systems were. With false color combination systems a different choice of colors or relative intensities might have produced either a more or less interpretable image. For the two electronic systems (IDECS and Philco-Ford), this restriction is more severe because of the large number of possible enhancement/color assignment combinations. Thus, the selection of the particular enhancement used was based on operator judgment of control settings, which probably was sub-optimal in each case.

---

[1] "Omission" is defined as the complement of "correct", ie, % Omission = (100-%C). "Commission", on the other hand, is defined as the actual number of errors committed (eg, calling a field "alfalfa" when in reality it is a barley field), expressed as a percent. Thus,

$$\%\ \text{Commission} = \frac{\text{Total number of commission errors}}{\text{Total possible responses - total possible correct responses}} \times 100$$

4.0 EXPERIMENTAL DESIGN

4.1 Experimental Hypothesis

This experiment was based on the hypothesis that different types of imagery exhibit different degrees of interpretability for particular earth features. If indeed this assumption is correct, these differences should permit the types of imagery to be ranked according to interpretability, feature by feature. The experiment was designed to hold all other factors as nearly constant as possible so that, when the interpretability of any given feature was being tested, the only variable would be the imagery itself. This variability manifested itself quantitatively in terms of both the time and accuracy of interpretation of each particular feature as a function of the type of imagery. Accuracy ratings took into consideration the correct responses, errors of omission, and errors of commission.

4.2 Statistical Array

The experiments performed involved the use of nine different kinds of imagery (from both photographic and enhancement systems) for the interpretation of four discrete categories, and a fifth category which combined all four categories for any of the given areas. This produced a 5 x 9 array in which there were 45 individual cells, each cell representing a unique combination of a particular category with a particular type of imagery. This required a minimum of 45 interpreters in order to fill each cell with an individual interpreter, minimizing the problem of area familiarization. In addition, it was considered to be more valid statistically to have several replications per cell (at least three replications being a minimum requirement).

4.3 Selection of Interpreters

The 45 interpreters that were required for these tests were selected in such a way that they could be placed into three groups of 15 each according to their level of competence (high, medium, and low) based on background data sheets filled out by the interpreters. A "high" (highly skilled interpreter) was ranked as such if he had

taken a remote sensing course and also had several years of work experience in the field; a "medium" was one who had taken a course in air photo interpretation or remote sensing but had little work experience in the field; and a "low" was one who had neither taken a course nor had obtained any work experience in the field. Each person was then randomly assigned to each of three cells such that each of the 45 cells contained a high, medium and low interpreter. This was accomplished in a manner such that no person would look at one of the four areas more than three times. This arrangement kept the problem of area familiarization to a realistic minimum. It reduced the problem of interaction between the categories to be interpreted in a given area, and it also permitted three replications per cell for more valid statistical results. By establishing each cell as equivalent to any other cell in terms of level of competence, this test allowed meaningful comparisons to be made between cells (image types) by category.

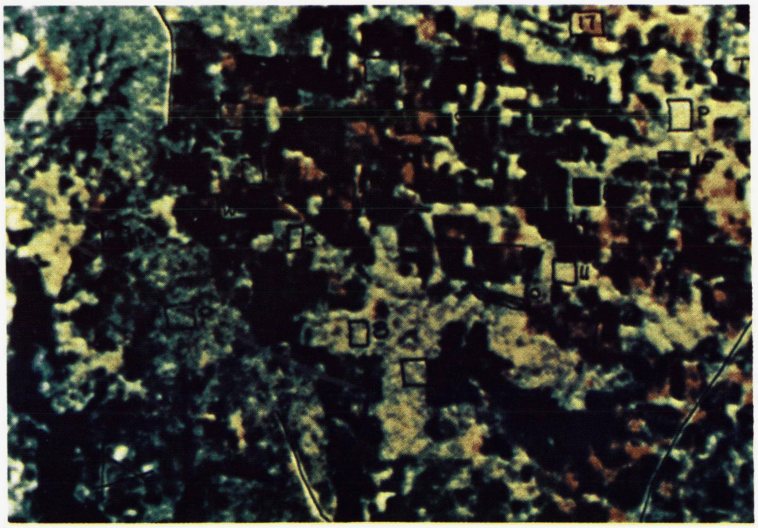
4.4 Interpretation Testing Procedures

For two reasons, administration of the actual interpreter tests was performed by the researchers: (1) to answer any questions which the interpreters might have about specific aspects of the test, and (2) to keep an accurate record of the time which each interpreter required to complete a particular test. At the outset, two methods of presenting images to the interpreter were tested, one employing prints and a second requiring projection of the images onto a viewing screen. One area was used as a control and an equal number of skilled and unskilled interpreters were asked to interpret individual categories in the same manner as detailed in the basic test procedure seen below. Statistically, no significant difference was noted between the interpretations accomplished using prints and those using projection techniques. Consequently, the researchers were able to choose what they considered to be the optimum method for presenting to the interpreter the test material for a given site. The actual tests were administered individually with a particular interpreter looking at one category on a discrete image type at one time.

When prints were employed, the interpreter was asked to identify particular categories in a prediction area based on information given in a training area on the same image. Information for the training samples was derived from available

"ground truth" maps of the test areas. The interpreters were required to record their identifications on a map where the prediction samples and training samples were delimited.

Figure 4.2-1, an infrared Ektachrome image of the Dallas-Fort Worth test site, represents another method of presenting the data to the interpreter. Prints 8 by 10 inches were used in these cases. Here the training and prediction areas were inked directly onto the print's surface. Each training area was labeled with an initial indicative of its category (T - trees, W - wheat, etc.) while prediction areas were numbered sequentially from 1 through 21. The interpreter was given an answer sheet on which was specified the name of the category that he was to interpret. Entries on the sheet also indicated the area and image type and provided space for name, date and time. The remainder of the sheet contained numbers followed by blank spaces corresponding to the numbers of the prediction areas labeled. By this means the results obtained could readily be analyzed in terms of correct answers, omission errors, commission errors, and time required to complete the test.



NOTE: TRAINING AND PREDICTION AREAS ARE INKED DIRECTLY ON THE PRINT'S SURFACE. THE LETTERED SQUARES INDICATE TRAINING AREAS WITH INITIALED CATEGORIES: T - TREES, W - WHEAT, ETC. NUMBERED SQUARES DENOTE PREDICTION AREAS.

Figure 4.2-1 Apollo Infrared Ektachrome of Dallas-Fort Worth Test Site

4.5 Scope of Analysis

The time and accuracy information was used as raw data for a computer program specifically selected for this experiment. The statistical methodology of this program is described in paragraph 4-6. The computer listing consisted of a one-way analysis of variance table which supplied the observed F ratio for each category. These F ratios formed the basis for the image rankings by categories on the computer listing. A Duncan multiple range test was then applied to the ranked data for each category in order to determine whether differences existed in the data at the 5% level of significance. Further analyses of the raw data and image rankings were made by manual calculation.

The purpose of these various calculations was to achieve the following objectives:

a. To determine the percent time and accuracy of interpreters at each level of competence

b. To rank the types of imagery by individual categories for each area according to correct responses, errors of commission and time

c. To rank the types of imagery by individual categories for each area according to a composite score of time and accuracy through the linear combination of the percent scores for omission errors, commission errors and time.

4.6 Statistical Model

In this experiment there are k (8 or 9) types of imagery to be ranked for each category within each area. The statistical model for this experiment can be considered a one-way classification with n(3) replications. Therefore, the completely randomized design is most suitable for our analysis.

The linear model for this design is:

$$X_{ij} = \mu + \alpha_i + \epsilon_{ij} \qquad i = 1, 2, \ldots k \; ; \; 1, 2, \ldots n$$

where μ is the general mean, α_i is the main effect for the i th image, and ϵ_{ij} is the experimental error for the j th replication on the i th image.

To test the significance of difference of the main effects for the images, the various mean squares and F ratio need to be computed under the null hypothesis:

$$H_o = \alpha_i = o \qquad \text{for all } i = 1, 2, \ldots k.$$

Based on the above model, the sums of squares can be obtained as follows:

$$\text{Total sum of square (TSS)} = \sum_{i=1}^{k} \sum_{j=1}^{n} x_{ij}^2 - C$$

$$C = \frac{1}{k \times n} \left(\sum_{i=1}^{k} \sum_{j=1}^{n} x_{ij} \right)^2$$

$$\text{Between image groups sum of square (BSS)} = \frac{1}{n} \sum_{i=1}^{k} \left(\sum_{j=1}^{n} x_{ij} \right)^2 - C$$

Within image groups sum of square or error sum of square

$$\text{(ESS)} = \text{TSS} - \text{BSS} = \sum_{j=1}^{3} (x_{ij} - \bar{x}_i)^2$$

The analysis of variance table for this one-way classification is:

Source	Sum of Square	Degree of Freedom	Mean Square	F Ratio
Between Group	BSS	k-1	BSS/K-1	MSB/MSE
Within Group	ESS	(n-1) k	ESS/(n-1)k	
Total	TSS	n x k - 1		

The computer F ratio is significant if it exceeds the theoretical F value that is obtained from an F table. If F is greater than $F\ k-1_{\alpha},\ (n-1)k$, the null hypothesis that there is no difference between the images can be rejected with a $(1 - \alpha)$ level of confidence.

If the null hypothesis is rejected, an additional multiple comparison should be made to rank those images. Since the size of the treatment groups is large, the most appropriate method is a multiple range test.

The procedure followed in a multiple range test is:

1. Determine $S_{\bar{x}} = \sqrt{\text{Mean Square Error}/n}$

   with DFE = (n-1)k

2. From the table of Significant Studentized Range points (SSR) obtain Significant Range Distribution.

   $SSR \left(\overset{DFE}{\underset{\rho_s}{p}} \right).$

   where DFE = (n-1)k

   p (the sizes referring to the number of means involved in a comparison) = 2 to k.

   ρ_s (level of significance) = α

3. Compute Least Significant Range (LSR)

$$LSR\left(\begin{matrix}p\\ p_s\end{matrix}\right) = SSR\left(\begin{matrix}DFE\\ p\\ \rho_s\end{matrix}\right) \times S_{\bar{x}}$$

4. Rank the means ($\bar{x}_1$, $\bar{x}_2 \ldots \bar{x}_k$) into ordered means

   $x(1) \geq x(2) \geq \ldots \geq x(k)$

5. Test the differences in the following order:

   $x(1) - x(k) \quad x(2) - x(k) \ldots\ldots x(k-2) - x(k) \quad x(k-1) - x(k)$

   $x(1) - x(k-1) \quad x(2) - x(k-1) \ldots x(k-2) - x(k-1)$

   $\vdots \qquad \vdots$

   $x(1) - x(2) \quad x(2) - x(3)$

   If any of these differences exceeds the appropriate LSR $\left(\begin{matrix}p\\ \rho_s\end{matrix}\right)$, we declare that this difference is significant at an α level of significance.

6. The results of the test can be summarized as several homogeneous subsets. The ranking is then based on those homogeneous subsets. In order to illustrate the above theoretical approach, the following example is given:

   Imperial Valley HF (ie, "high-flight" photography): % correct for bare soil*

Analysis of Variance Table

Source	SS	DF	MS	F Ratio
Between groups	3692.0000	7	527.4286	4.6848*
Error	1801.3333	16	112.5833	
Total	5693.3333	23		

$$F_{0.05}\ 7,16 = 2.66$$

Since F ratio = 4.6868 > 2.66

$\therefore$ reject H_o.

* In this test, 5% level of significance is used.

5% Multiple Range Test

Treatment #(i)	Label	Mean ($\bar{X}_i$)
1	25A	71.000
2	58	77.000
3	89B	56.333
4	PF	31.667
5	FRSL	62.000
6	CIR	59.333
7	IDECS	59.333
8	CIR+IDECS	60.667

(1) $S_{\bar{x}} = \sqrt{MSE/n} = \sqrt{\frac{112.5833}{3}} = 6.1259$

with DFE = 16

(2)

Value of p	2	3	4	5	6	7	8
SSR	3.00	3.15	3.23	3.30	3.34	3.37	3.39
LSR	18.378	19.297	19.787	20.216	20.661	20.644	20.767

where SSR $\left(\begin{smallmatrix} 16 \\ p \\ 0.05 \end{smallmatrix} \right)$ for p = 2 to 8 are obtained from the significant points of the Studentized Range Distributions.

$$LSR \left({}^{p}_{0.05} \right) = SSR \left(\begin{smallmatrix} 16 \\ p \\ 0.05 \end{smallmatrix} \right) \times S_{\bar{x}} .$$

(3)

Rank (i)	Ordered Mean x(i)	Label
1	77.000	58
2	71.000	25A
3	62.000	FRSL
4	60.667	CIR+IDECS
5	59.333	CIR
6	59.333	IDECS
7	56.333	89B
8	31.667	PF

Compare 58 with all the rest:

$x(1) - x(8) = 45.333 > 20.767 = LSR \binom{8}{0.05}$ significant

$x(1) - x(7) = 20.667 > 20.644 = LSR \binom{7}{0.05}$ significant

$x(1) - x(6) = 17.667 < 20.461 = LSR \binom{6}{0.05}$ not significant

Compare 25A with all the rest:

$x(2) - x(8) = 39.333 > 20.644 \quad LSR \binom{7}{0.05}$ significant

$x(2) - x(7) = 14.667 < 20.461 \quad LSR \binom{6}{0.05}$ not significant

Therefore we have 2 homogeneous subsets:

(58, 25A, FRSL, CIR + IDECS, CIR, IDECS)
(25A, FRSL, CIR + IDECS, CIR, IDECS, 89B)

The results of the test can be summarized as follows:

58 25A FRSL CIR + IDECS CIR IDECS 89B PF

Any two means not underscored by the same line are significantly different at 5% level. Any two means underscored by the same line are not significantly different from one another. Based on those homogeneous subsets, the overlap part of the two lines can be grouped as one rank. Therefore, the following rankings for % correct can be made:

Rank	Imagery
1	58
2	25A FRSL CIR + IDECS CIR IDECS
3	89B
4	PF

5.0 EVALUATION OF STATISTICAL RESULTS

5.1 Summary

To review the approach followed in this report presumes that the best way to evaluate the capabilities of an electronic processor such as IDECS is to compare it with other enhancement systems under development (eg, Philco-Ford's image tone enhancement system) and with imagery obtained by photographic systems that are commonly utilized by researchers in the field, such as Ektachrome, infrared Ektachrome, or Pan 25A photography. This has been done by the administration of photo interpretation tests for specific categories.

5.2 Method of Stastistical Analysis

The raw data were run through a specially selected computer program to consolidate the information into a more manageable form for statistical analysis. A computerized statistical analysis of the printout was made in order to determine whether significant differences existed in the abilities of interpreters to identify discrete categories in the test areas on imagery from the enhancement and photographic systems utilized in this research project. Rankings of the original data from the statistical tests were made in terms of correct responses, fewest commission errors, least time, and lowest total by individual categories. The first-listed image in the ensuing rankings is always the best (most interpretable) image for that category. This procedure ranking from best to worst is followed for the statistically derived rankings, not only when such rankings have statistical validity but also when no statistical ranking is valid.

5.3 Significance Level Rankings of Analysis of Variance Data

Tables 4.2-1 through 4.2-10 contain the ranking derived from the application of the multiple range test at the 5% level to the one-way analysis of variance of the raw data by categories at each of the four test sites.

TABLE 4.2-1

IMPERIAL VALLEY HIGH FLIGHT - BARE SOIL RANKINGS

Correct		Commission		Time		Total	
1	58		FRSL	1	FRSL	1	FRSL
	25A		IDECS		IDECS		25A
	FRSL	1	CIR		CIR		IDECS
2	CIRID		25A		CIRID	2	CIR
	CIR		CIRID	2	PF		CIRID
	IDECS		PF		89B		58
3	89B		89B		58	3	89B
4	PF	2	58		25A	4	PF

Key:

25A	=	Panchromatic film with a Wratten 25A filter
58	=	Panchromatic film with a Wratten 58 filter
89B	=	Black-and-white infrared film with a Wratten 89B filter
CIR	=	Infrared Ekachrome film with a Wratten 15 filter
FRSL	=	Forestry Remote Sensing Laboratory optical combiner image
PF	=	Philco-Ford electronic combiner image
IDECS	=	University of Kansas electronic combiner image
CIRID	=	A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

Remarks:

On the basis of the multiple range test given at the 5% level to the raw scores for identification of bare soil from high flight imagery in the Imperial Valley, IDECS ranks among a homogeneous group of image types as second in the "correct" column. IDECS ranks among a homogeneous subset as first in the "commission" column while falling into a homogeneous subset ranked second for "time". For "time", IDECS and all other images differed from the Forestry Remote Sensing Laboratory optically combined image at the 5% significance level. For "total", IDECS also ranked second in a subset which includes the Pan 25A; infrared Ektachrome; a combined interpretation of color, infrared Ektachrome, and IDECS; and the Pan 58 image.

TABLE 4.2-2

IMPERIAL VALLEY HIGH FLIGHT - CROPLAND RANKINGS

Correct	Commission		Time	Total
IDECS	CIRID	1	IDECS	CIRID
CIRID	PF		PF	CIR
CIR	FRSL		CIR	FRSL
FRSL	CIR	2	CIRID	IDECS
58	58		FRSL	PF
25A	89B		25A	58
PF	IDECS		58	25A
89B	25A	3	89B	89B

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images.

Remarks:

Of the four criteria (correct, commission, time and total) only the "time" data exhibited any significant differences at the 5% level. In these rankings for cropland, IDECS is first by itself, differing from all other image types at a 5% level of significance.

TABLE 4.2-3

IMPERIAL VALLEY HIGH FLIGHT - ALFALFA RANKINGS

Correct	Commission		Time	Total
58	1	CIRID	FRSL	CIR
89B		IDECS	CIR	IDECS
CIR		FRSL	CIRID	89B
PF		PF	PF	PF
IDECS	2	CIR	25A	CIRID
25A		89B	58	FRSL
FRSL		25A	IDECS	25A
CIRID	3	58	89B	58

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared, Ektachrome and University of Kansas electronic combiner images.

Remarks:

The Imperial Valley "high-flight" rankings for alfalfa are significant at the 5% level only in terms of the "commission" category. Here IDECS ranks first in a homogeneous subset along with the combination of color, infrared Ektachrome and IDECS.

TABLE 4.2-4

IMPERIAL VALLEY HIGH FLIGHT - BARLEY RANKINGS

	Correct		Commission		Time		Total
1	IDECS	1	CIR		CIR		FRSL
	FRSL		CIRID	1	58		IDECS
	CIRID		IDECS		FRSL	1	CIRID
2	25A		89B		89B		CIR
	58	2	25A	2	IDECS		25A
	89B		FRSL		25A		58
	CIR		PF		CIRID		89B
3	PF	3	58	3	PF	2	PF

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

Remarks:

Results shown here are at the 5% level of significance and apply to the multiple range test, based on interpretation tests scores for the category "Barley" on the Imperial Valley High Flight imagery. These results show that IDECS scores in the highest rank for "correct" and "total", while falling into the second level for "commission" and "time". In the "correct" ranking, IDECS is alone at the highest rank while for "total", IDECS shares first with all other images except Philco-Ford.

TABLE 4.2-5

IMPERIAL VALLEY HIGH FLIGHT - BARE SOIL VS. CROPLAND

	Correct		Commission		Time	Total
	CIRID		CIRID	1	FRSL	CIR
1	25A		25A		IDECS	FRSL
	CIR	1	CIR		CIR	CIRID
	FRSL		IDECS	2	58	58
	58		FRSL		CIRID	25A
2	89B		58		89B	89B
	PF	2	89B	3	25A	PF
3	IDECS		PF		PF	IDECS

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

Remarks:

For "commission" as determined from the Imperial Valley "high flight" data (based on the bare soil vs. cropland category) IDECS is found in a homogeneous subset at the highest rank. IDECS ranks in the second homogeneous subset at the 5% significance level for "time" and ranks third for "correct". The "total" data (far right column) show no significant difference in the interpretability of features attributable to image type.

TABLE 4.2-6

IMPERIAL VALLEY APOLLO - BARE SOIL RANKINGS

	Correct		Commission	Time	Total
1	PF		89B	CIRID	CIR
	58		CIR	IDECS	PF
	CIR		CIRID	89B	IDECS
	IDECS	1	FRSL	CIR	89B
2	CIRID		IDECS	PF	CIRID
	25A		COLOR	FRSL	58
	89B		25A	58	25A
	COLOR		PF	25A	FRSL
3	FRSL	2	58	COLOR	COLOR

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

COLOR = Color aerial film

Remarks:

Rankings for interpretability of the bare soil category on the Imperial Valley Apollo imagery show no significant differences in the data for "time" and "total". For "correct", IDECS is ranked second in a homogeneous subset with all image types except Philco-Ford (which is ranked first) and the Forestry Remote Sensing Laboratories optical combiner (which is ranked third). IDECS is ranked first with all other images with the exception of Philco-Ford and Pan 58 for "commission".

TABLE 4.2-7

IMPERIAL VALLEY APOLLO - CROPLAND RANKINGS

	Correct	Commission	Time		Total
	89B	25A	IDECS		IDECS
	FRSL	IDECS	COLOR	1	25A
	CIR	PF	CIRID		CIRID
1	CIRID	CIRID	58		FRSL
	25A	CIR	FRSL		CIR
	COLOR	FRSL	PF	2	89B
	IDECS	COLOR	CIR		COLOR
2	58	58	89B		PF
	PF	89B	25A	3	58

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

COLOR= Color aerial film

Remarks:

Significance level rankings for the cropland category show IDECS among the images ranking first in all criteria. There are no significant differences in the rankings for "commission" and "time". IDECS-enhanced imagery when viewed alone ranks first with Pan 25A and with the combination of color infrared, Ektachrome and IDECS in the "total" criterion (the linear combination of "omission", "commission", and "time"). For "correct", IDECS ranks first with all other images (except for Pan 58 and Philco-Ford).

TABLE 4.2-8

IMPERIAL VALLEY APOLLO - ALFALFA RANKINGS

	Correct		Commission		Time	Total
1	FRSL	1	CIRID	1	COLOR	COLOR
2	89B	2	PF	2	89B	FRSL
	COLOR		IDECS		58	58
	58		58		25A	89B
	25A		CIR		IDECS	25A
	PF		COLOR		CIRID	IDECS
	CIR		25A		FRSL	PF
	IDECS		89B		CIR	CIR
3	CIRID	3	FRSL	3	PF	CIRID

Key:

25A	=	Panchromatic film with a Wratten 25A filter
58	=	Panchromatic film with a Wratten 58 filter
89B	=	Black-and-white infrared film with a Wratten 89B filter
CIR	=	Infrared Ektachrome film with a Wratten 15 filter
FRSL	=	Forestry Remote Sensing Laboratory optical combiner image
PF	=	Philco-Ford electronic combiner image
IDECS	=	University of Kansas electronic combiner image
CIRID	=	A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images
COLOR	=	Color aerial film

Remarks:

IDECS ranks consistently second in the significance level ranking for the Imperial Valley Apollo imagery alfalfa category, with the exception of the "total" criterion. No significant difference was detected for "total" in the data when using the multiple range test at the 5% level. For "correct", IDECS ranks in a homogeneous group of imagery behind the Forestry Remote Sensing Laboratory optical combiner, while ranking behind the combination of color, infrared Ektachrome and IDECS for "commission" and behind color for "time."

TABLE 4.2-9

IMPERIAL VALLEY APOLLO - BARLEY RANKINGS

Correct		Commission	Time	Total
COLOR	1	CIR	CIRID	CIRID
58		CIRID	IDECS	IDECS
PF		IDECS	FRSL	COLOR
CIR	2	89B	89B	89B
IDECS		FRSL	COLOR	58
89B		COLOR	25A	CIR
CIRID		25A	58	FRSL
25A	3	PF	PF	PF
FRSL		58	CIR	25A

Key:

25A	=	Panchromatic film with a Wratten 25A filter
58	=	Panchromatic film with a Wratten 58 filter
89B	=	Black-and-white infrared film with a Wratten 89B filter
CIR	=	Infrared Ektachrome film with a Wratten 15 filter
FRSL	=	Forestry Remote Sensing Laboratory optical combiner image
PF	=	Philco-Ford electronic combiner image
IDECS	=	University of Kansas electronic combiner image
CIRID	=	A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images
COLOR	=	Color aerial film

Remarks:

No significant differences in the image types tested for barley in the Imperial Valley Apollo were obtained at the 5% level in the significance level rankings for "correct", "time", or "total". For "commission", IDECS ranks at the second level behind infrared Ektachrome, which ranks first.

TABLE 4.2-10

IMPERIAL VALLEY APOLLO - OVERALL RANKINGS

Correct	Commission		Time		Total
CIRID	CIRID	1	CIRID	1	CIRID
CIR	CIR		IDECS		CIR
PF	PF		FRSL		FRSL
FRSL	FRSL		CIR	2	PF
25A	25A	2	COLOR		25A
COLOR	COLOR		PF		COLOR
IDECS	IDECS		58		IDECS
89B	89B		25A		58
58	58	3	89B	3	89B

Key:

25A = Panchromatic film with a Wratten 25A filter

58 = Panchromatic film with a Wratten 58 filter

89B = Black-and-white infrared film with a Wratten 89B filter

CIR = Infrared Ektachrome film with a Wratten 15 filter

FRSL = Forestry Remote Sensing Laboratory optical combiner image

PF = Philco-Ford electronic combiner image

IDECS = University of Kansas electronic combiner image

CIRID = A combined interpretation of color, infrared Ektachrome and University of Kansas electronic combiner images

COLOR = Color aerial film

Remarks:

In the "overall" (bare soil vs cropland) category of the Imperial Valley Apollo imagery, no significant difference is seen in the rankings for "correct" and "commission". IDECS ranks in a homogeneous subset at the second level behind the combination of color, infrared Ektachrome and IDECS in both "time" and "total". It is to be emphasized that IDECS equipment, when properly used as in these tests, will rarely if ever produce a single image of high quality for "overall" interpretation, ie, a single image that is optimum for the identification of many categories of features. Instead, IDECS usually is best used to form a series of enhancements, the first of which is designed to discriminate all features in "category A" from everything else, the second to discriminate all features in "category B" from everything else, etc.

6.0 CONCLUSIONS

The results of the statistical analyses point to several conclusions: (1) interpreters are able to perceive color differences more quickly and accurately than gray-level differences; (2) for orbital photography (low resolution imagery), discrete color differences are more valuable for interpretation than colors that grade subtly into one another; (3) for high altitude photography, distinct color variation and IDECS quality resolution are competitive with high resolution systems that exhibit inter- and intra-color gradations; and (4) for low altitude photography, color differences are more important than grey level differences and resolution assumes greater importance because interpreters tend to focus their attention on geometry more often than on color or tonal patterns.

The conclusions stated above point to several more specific conclusions that can be made concerning the interpretability of IDECS imagery:

- For high altitude and satellite photography, IDECS is highly competitive with other systems tested, and better than many. This high ranking can be attributed to the fact that IDECS organizes data into discrete color amalgamations and possesses compatible resolution capabilities for imagery of high altitude and satellite scales.

- For low altitude photography, the generalizing advantage of IDECS is handicapped by the incompatibility of its resolution when compared with the resolution of the input imagery. Although IDECS may be able to detect the important differences that are observable at this scale, it does not have the necessary resolution to display them for interpretation as adequately as the higher resolution input imagery.

- Highly skilled interpreters tend to interpret IDECS imagery faster and more accurately than medium or low skilled interpreters. There is no consistent difference that can be detected (in terms of time and accuracy) between the performances of medium and low skilled interpreters.

- This quantitative evaluation experiment indicates that IDECS is competitive with other enhancement and photographic systems as an aid to interpretation of earth features on the basis of time and accuracy. Limitations are evident when IDECS is compared with low altitude, high resolution photography.

SECTION 4.3

APOLLO 9 SCIENTIFIC EXPERIMENT NO. 065

Performed Under the Auspices

of

NASA's EARTH RESOURCES PROGRAM

US Departments of Agriculture and Interior

US Naval Oceanographic Office

1969

by

Dr. R. N. Colwell
Professor of Geography
Forestry Remote Sensing Laboratory
Department of Geography
University of California
Berkeley, California

SECTION 4.3
TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

1.0 INTRODUCTION

This study was performed under the direction of Dr. R. N. Colwell, Professor of Geography, a forestry research specialist and associate of the Forestry Remote Sensing Laboratory (FRSL), Department of Geography, the University of California at Berkeley, California.

The primary objective of this study was to develop improved capabilities for the inventory of various kinds of earth resources, including timber, forage, agricultural crops, soils, minerals, and water. This report is presented as an extract from the University of California report, "An Evaluation of Earth Resources Using Apollo 9 Photography."

2.0 THE NATURE OF THE EXPERIMENT

Apollo 9 scientific experiment No. 065 (S065) was performed under the auspices of NASA's Earth Resources Program, in cooperation with various other government agencies, including the U.S. Departments of Agriculture and the Interior, ESSA, and the U.S. Naval Oceanographic Office. Several universities and private industrial firms, under the direction of NASA, also participated in the important data-collection phase.

3.0 SCOPE

A rationale for the S065 experiment was developed with emphasis on its great potential importance. A description is given of the types of photography used during the flight of Apollo 9 and of supporting photography obtained simultaneously from high-flying aircraft or from direct on-the-ground observation. A description of photography made by "high-flying" aircraft in support of the S065 experiment is also described.

4.0 JUSTIFICATION FOR THE STUDY

The United Nations has stated that, to provide a decent level of nutrition for the world's people, the production of food will have to be doubled by 1980 and trebled by the year 2000. In recent testimony, given to the U.S. House of Representatives by personnel of the lumber and housing industries, there was a concensus of opinion that 26 million homes must be built within the next decade. This represents a construction rate triple the present rate, with a proportionate increase in the demand for lumber and other construction materials. At the estimated consumption rate, the U.S. Department of the Interior has warned repeatedly that the presently known reserves of copper, lead, and zinc, as well as many other important nonrenewable mineral resources, will be exhausted within the next two or three decades.

The few circumstances just cited suggest a critical need for immediate and judicious management of the earth's resources. An important first step leading to such management is to obtain accurate resource inventories quickly, and at frequent intervals.

5.0 RATIONALE FOR THE USE OF AIRCRAFT AND SPACECRAFT WHEN MAKING EARTH RESOURCE SURVEYS

There are two primary reasons why earth resource surveys might best be made through the use of aircraft and spacecraft:

1. "The face of the land looks to the sky." The task of inventorying the earth's resources is, first of all, one of delineating boundaries between one resource characteristic and another. Confined to the surface of the earth, man has great difficulty in recognizing and delineating these boundaries. This is attributable mainly to limited visability of the terrain, especially in areas where the topography is heavily dissected.

2. Equipment capable of surveying and displaying conditions as they exist simultaneously over a broad area of the earth's surface must be utilized. It is only from "high-flying" aircraft or spacecraft that such a quick and economical delineation of the earth's resource features can be obtained. The fact that such vast expanses can be viewed at a single point in time and under relative uniform lighting conditions constitutes an additional advantage. The ability of aircraft and spacecraft to be able to travel quickly from one camera station to another is another important advantage.

Perhaps another advantage of aerial or space views is the ability to discern subtle contours and other features simultaneously over a vast area. Without this advantage a resource analyst might never become aware of their existence. Often, it is only this ability to see each part of a pattern in relation to all the other parts that we are able to distinguish a feature and thereby discover important earth resources associated with it.

Finally, aerial and space views of the earth's surface frequently can complement each other. The broad synoptic view obtained by space photography can be used to maximum advantage in drawing boundaries which discriminate one type of resource from another. Then, through a process known as "multistage sampling," very large scale aerial photography can be made of small representative areas within each type in order to identify it.

6.0 RATIONALE FOR THE USE OF BOTH COLOR AND MULTIBAND BLACK-AND-WHITE PHOTOGRAPHS

For the first time in history, simultaneous multiband photographs of the earth's surface were obtained from space by the crew of the Apollo 9 mission. The potential usefulness of such photography in making earth resource surveys is apparent.

Our ability to inventory earth resource features on multiband photography rests on the fact that every type of feature encountered on the surface of the earth tends to reflect and emit radiant energy in distinctive amounts at certain specific wavelengths. Consequently, when remote sensing is done simultaneously in each of several wavelength bands (a process variously known as "multiband sensing," "multispectral sensing" and "multiband spectral reconnaissance"), each type of feature theoretically becomes identifiable by virtue of its multiband "tone signature" or "spectral response pattern."

Therefore, a special NASA photographic team held a series of meetings, extending over a period of more than two years, for the primary purpose of selecting the three wavelength bands that would be most useful in a multiband space photography experiment.

Consistent with their recommendations, the three bands used by the Apollo 9 astronauts to obtain simultaneous black-and-white photographs from space were the green, visible red and near-infrared wavelengths of radiant energy.

Some investigators noted that a color film (infrared Ektachrome) contains three dyes responsive to green, red, and near-infrared. They proposed that this single color film would provide all of the information obtainable from three black-and-white photographs. In order to evaluate this observation, a fourth camera using infrared Ektachrome film was used on the Apollo 9 mission in conjunction with the three cameras using the black-and-white films. This four-camera package consisting of four Hasselblad cameras, having focal lengths of 80 mm and accommodating 70 mm roll film, was designated by the NASA photographic team as scientific experiment No. 065. Hereafter in this report, as elsewhere in the literature, photographs obtained on the Apollo 9 mission will be designated as "S065" photography.

7.0 ANALYSIS OF EARTH RESOURCES IN THE PHOENIX, ARIZONA AREA

On March 12, 1969, Apollo 9 obtained infrared Ektachrome and black-and-white multiband space photographs (referred to as "S065 photos") over Phoenix, Arizona. These photographs were taken from an altitude of 126 nautical miles (145 statute miles) at approximately 8:30 AM local time. On the same day a high performance aircraft obtained aerial photographs (referred to as "high-flight photos"), using essentially the same film-filter combinations, from an altitude of approximately 70,000 feet above sea level.

After the March Apollo 9 mission, high-altitude aerial photographs were taken of the Phoenix area on approximately monthly intervals for the purpose of studying such time-variant phenomena as agricultural crop development and transient range vegetation. The S065 photography and sequentially "high-flight" photos obtained by means of this experiment provided a unique opportunity to examine the usefulness of such photography for land use planning and earth resource inventory.

The area includes a variety of wildland and cultural features shown on three adjacent Apollo 9 space photos (AS-9-3800, -3801, and -3802). The area extends approximately 100 miles to the east and west of Phoenix. An analysis of the various film-filter combinations from space and the sequential aerial photos was made of this large area. A major objective of the experiment was to determine the specific applications and/or limitations of such photography for evaluating the resources of:

a. Agricultural lands
b. Range land
c. Geologic and hydrologic units
d. Urban and suburban areas

Within this large area, small representative test sites were selected to obtain detailed information regarding the condition and identity of features related to

land use categories (agriculture, range, geology-hydrology, and cultural development). "Ground truth" was acquired at the time of the Apollo 9 overflight and on subsequent dates coinciding with the "high-flights" (12 March, 23 April, 21 May, 12 July, 5 and 29 August). The ground information, used in conjunction with the sequentially obtained aerial photographs, provided the basis for evaluating the merits of the Apollo 9 space photographs and determined their usefulness either alone or in concert with the "high-flight" photographs for earth resource analysis of the Phoenix, Arizona area.

8.0 SUMMARY OF ANALYSIS OF SPACE PHOTOS OF THE PHOENIX, ARIZONA AREA

In the analysis of agricultural resources, it was found that acceptable estimates of crop area can be made from the space photographs (in particular, the infrared Ektachrome, Ektachrome, and Pan-25A photographs). However, crop identification exceeding 60% accuracy can rarely be made on any of the space photographs obtained 12 March 1969. This is mainly due to the fact that, in March, barley, mature alfalfa, wheat, and sugar beets have similar spectral signatures that were quite variable for crop type and overlapped one another, making accurate discrimination difficult. The infrared Ektachrome space photographs gave the best results for discriminating bare cultivated fields from cover crop categories (98% accuracy compared to 83% and 89% for Pan-25A and IR-89B). This information is particularly significant since nearly all fields, which appeared bare in March, were planted in cotton. Hence, an accurate inventory of the amount and distribution of cotton could be made. Although citrus crops are not grown in the agricultural test site near Mesa, elsewhere they can be differentiated from cover crops on infrared Ektachrome photographs by virtue of their unique color signature.

Color composites, made from black-and-white space photographs, permitted interpreters to differentiate bare cultivated fields more accurately than on any of the black-and white photographs alone (97% accuracy for the FRSL composite versus 83% and 89% for Pan-25A and IR-89B, respectively). Color composites did not, however, permit a more accurate identification of cover crop types because of the overlapping crop signatures on the black-and-white photographs.

The interpretive test results also indicate that crop categories can be interpreted as well on space photographs taken in March as on the aerial photographs taken at the same time. However, a significant increase in the accurate identity of crop types was achieved when sequentially obtained aerial photographs were interpreted concurrently, and when they were made into multidate color composites. From the preceding two observations it was concluded that sequentially obtained space photographs will be equally valuable for making accurate crop identifications. For example, sequentially obtained black-and-white space photographs exposed for the green, red, and near-infrared could be combined into either multidate or multiband color composites that could yield as much or more information than infrared Ektachrome space photographs. The possibilities for making color composites using different black-and-white spectral bands obtained at different dates have not yet been fully explored. However, the possibilities for increasing overall interpretability of agricultural features using these techniques are extremely promising.

9.0 ANALYSIS OF AGRICULTRAL RESOURCES IN THE IMPERIAL VALLEY, CALIFORNIA AREA

Mr. Randolph R. Thaman, Department of Geography, Forestry Remote Sensing Laboratory (FRSL), at the University of California, Berkeley, and currently on sabbatical leave in Tonga, South Pacific, conducted this study to determine the feasibility of making broad crop inventories from space photographs for the purpose of analyzing agricultural resources in the Imperial Valley of California.

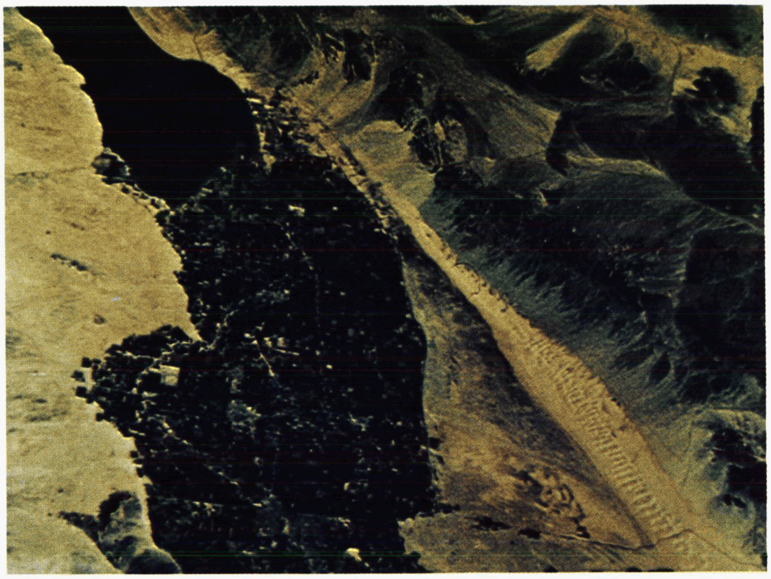
The differences between irrigated agricultural land, the surrounding wild land, and urban environments are easily detected on the S065 earth-orbital Apollo 9 photographs. The study (an analysis of S065 photographs taken by the Apollo 9 mission while over the Imperial Valley, California) concentrated on crop lands and not the wild lands or urban environments.

The Imperial Valley, figure 4.3-1, is located in the extreme southcentral part of California and extends from the Salton Sea on the north to the Mexican border on the south. It has an aerial extent of approximately 4,500 square miles. With almost a half million acres under cultivation, the Imperial Valley is the largest

single area of irrigated agriculture in the western hemisphere, with crop and livestock production grossing over $230,000,000 a year.*

The S065 photography used for this experiment consisted of the following:

1. Infrared Ektachrome film with a Wratten 15 filter (frame #A59-26A 3799A).
2. Panatomic-X film with a Wratten 58 filter (A59-26B-3799B).
3. Panatomic-X film with a Wratten 25A filter (A59-26D-3799D).
4. Infrared aerographic film with a Wratten 89B filter (A59-26C-3799C).



THIS FILM EMPLOYS A THREE-DYE EMULSION, EXPOSED FOR THE BLUE, GREEN, AND RED PORTIONS OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-1 Aerial Ektachrome (Conventional Color Film) Hand-Held Hasselblad Photograph Taken by the Apollo 9 Astronauts from an Altitude of 130 Nautical Miles Over Imperial Valley, California

---

* The Imperial Valley, Windsor Publications, Encino, California, 1968, page 4.

As an additional accessory in the evaluation of S065 photography, complementary vertical and oblique low-altitude aerial photographs were made simultaneously with the Apollo 9 spacecraft by Airview Specialists Corporation of Palo Alto, California. These pictures showed representative examples of color and tonal variation between the different fields due to crop types and field conditions. Ground truth information was acquired at six different points in time. The first date was coincident with the S065 experiment on 12 March 1969, and others, at times when the monthly sequential NASA "high-flight" missions were made. This information, plus the photography obtained during the "high-flight" missions, determined to a large extent the validity of crop inventory obtained by space photography.

The S065 photography of the Imperial Valley is of high quality. Figures 4.3-2 and 4.3-3 show examples of photographs obtained with the four cameras from an altitude of 129 nautical miles on 12 March 1969.

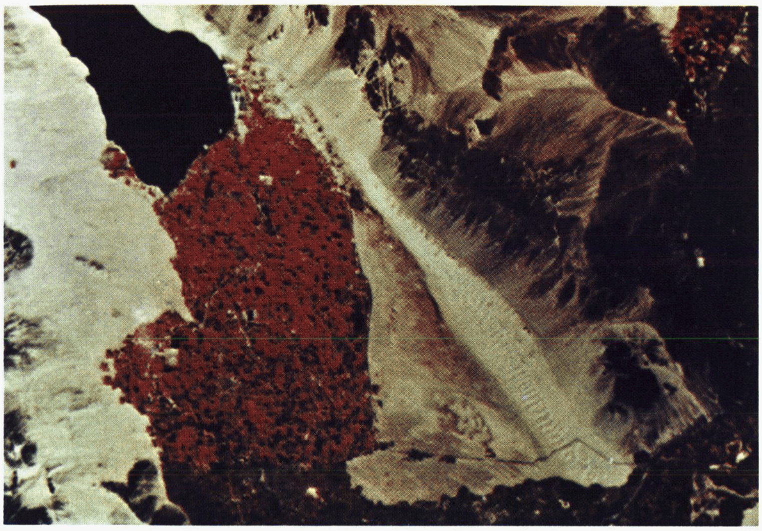
It is evident from the photographs shown in figures 4.3-2 through 4.3-5 that most of the individual fields are easily discernable. Since definite color and tonal differences are detectable between fields, identification of individual crop types and field conditions will also be discernable.

A number of photo intepretation tests were conducted to determine the value of the acquired photographs. The tests were designed to determine to what extent the crops in a given test area can be differentiated. Concurrent with the Apollo 9 overflight, terrestrial photographs in color and color infrared were taken of the test area to document, field by field, the conditions of crop types.

10.0 IMAGE PREPARATION

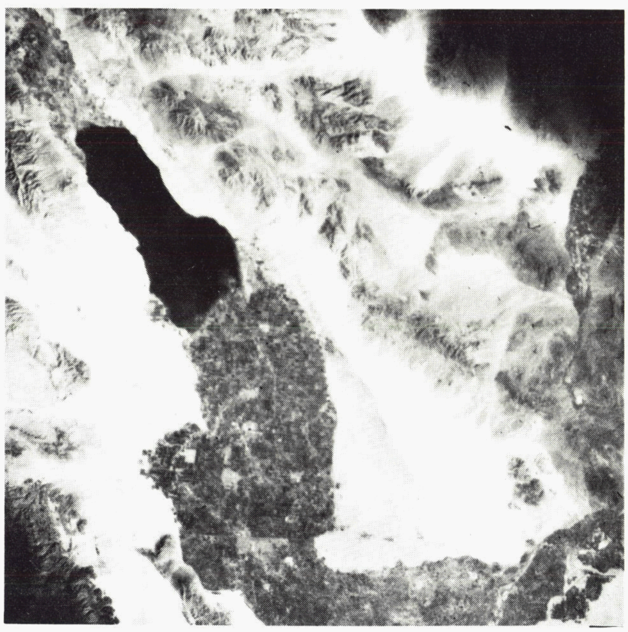
The following photographs were used for the interpretation test:

- 20-diameter enlargements of S065 transparencies
- NASA high-altitude images enlarged to the same scale
- Enhancements made from two or three of the above images



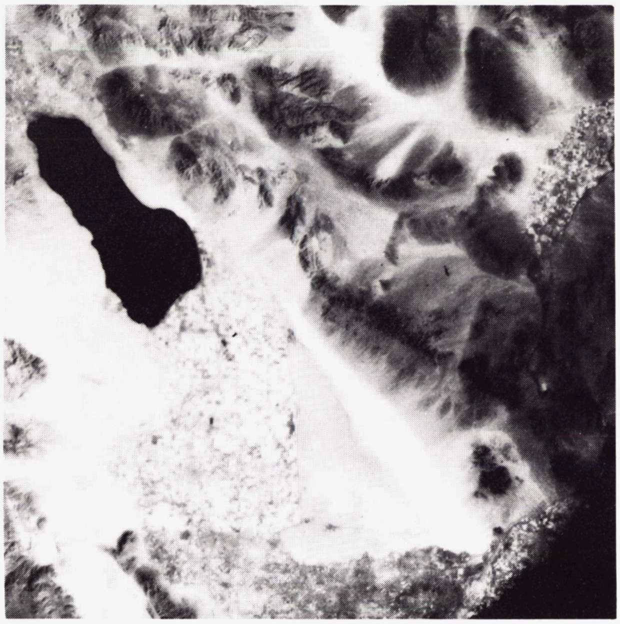
THIS FILM EMPLOYS A THREE-DYE EMULSION, EXPOSED FOR THE GREEN, RED, AND REFLECTIVE INFRARED PORTIONS OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-2 Infrared Ektachrome S065 Photograph Taken by the Apollo 9 Astronauts



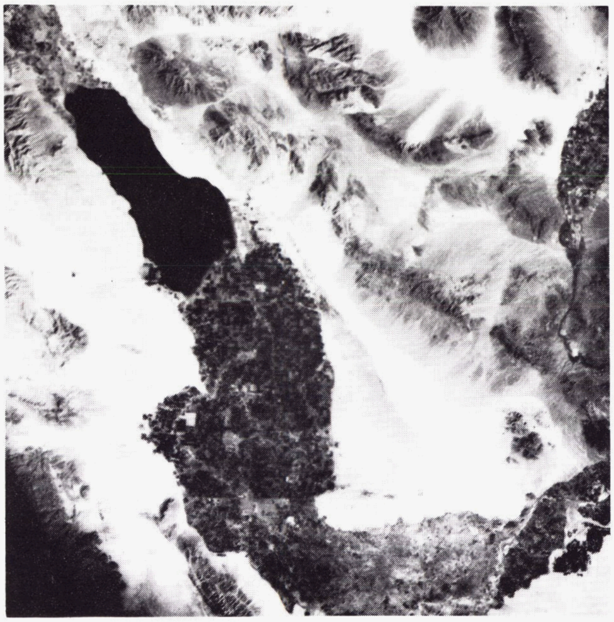
THIS FILM WAS EXPOSED FOR THE GREEN PORTION OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-3 Black-and-White S065 Photograph Taken with Panchromatic Film and a Wratten 58 Filter



THIS FILM WAS EXPOSED FOR THE REFLECTIVE INFRARED PORTION OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-4 Black-and-White S065 Photograph Taken with Infrared Film and a Wratten 89B Filter



THIS FILM WAS EXPOSED FOR THE RED PORTION OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-5 Black-and-White S065 Photograph Taken with Panchromatic Film and a Wratten 25A Filter

The test images are as follows:

Apollo - S065	NASA High Altitude
Ekta-Aero infrared	Ekta-Aero infrared
Panchromatic (Wratten 58)	Panchromatic (Wratten 58B)
Infrared (Wratten 89B)	Infrared (Wratten 89B)
Panchromatic (Wratten 25A)	Panchromatic (Wratten 25A)
Forestry Remote Sensing Lab enhancement	Forestry Remote Sensing Lab enhancement
Philco-Ford enhancement	Philco-Ford enhancement

The test images were converted into either 3-1/4 by 4-inch latern slides or 35 mm slides, which are then projected on a screen for visual interpretation. These images measured approximately 13 by 18 inches, and were viewed from a distance of approximately 12 feet.

11.0 EXPERIMENTAL DESIGN

In order to obtain quantitative measures of interpretation accuracy, a photo interpretation test was designed and given to a number of the interpreters.

From a study of the results, it appears that two types of imagery seem to produce results that are significantly more interpretable than others. These two image types are the infrared Ektachrome image and the FRSL optical enhancement shown in figures 4.3-6 through 4.3-10. An image-by-image evaluation, starting with the most interpretable image and concluding with what appears to be the least interpretable from the results of the study, is presented on the following pages.

The FRSL enhancement ranked highest on almost all of the overall rankings, as shown in tables 4.3-1 through 4.3-3. Presumably, this result was obtained because

TABLE 4.3-1

RANKING OF DIFFERENT TYPES OF IMAGERY FOR "PERCENT CORRECT" (ALL 6 CATEGORIES)

S065 Apollo Imagery*		High-Flight Imagery	
Imagery	Percent Correct	Imagery	Percent Correct
IR Ektachrome	46.17	IR Ektachrome	52.25
FRSL	46.16	Pan 25A	51.96
Pan 25A	43.63	IR 89B	49.10
IR 89B	42.57	Philco-Ford	47.60
Philco-Ford	39.03	FRSL	39.43
Pan 58	30.10	Pan 58	37.70

TABLE 4.3-2

RANKING OF DIFFERENT TYPES OF IMAGERY FOR "PERCENT COMMISSION ERRORS" (ALL 6 CATEGORIES).

In this table, the lower the percentage figure, the more interpretable the imagery.

S065 Apollo Imagery*		High-Flight Imagery*	
Imagery	Percent Commission	Imagery	Percent Commission
IR Ektachrome	49.27	IR Ektachrome	50.16
IR 89B	52.13	Pan 25A	55.54
FRSL	57.19	FRSL	55.80
Philco-Ford	60.07	IR 89B	62.45
Pan 25A	61.71	Philco-Ford	65.89
Pan 58	71.76	Pan 58	71.77

* Statistically significant differences in interpretability of image types were found for these tests.

a. This image combines spectral signatures from more than one band, thereby enabling all the information from two or three bands to be seen simultaneously.

b. The resolution is quite good.

c. The color combinations can be varied to provide optimum interpretability.

TABLE 4.3-3

RANKING OF DIFFERENT TYPES OF IMAGERY FOR AVERAGE TIME IN MINUTES PER IMAGE (ALL 6 CATEGORIES).

S065 Apollo Imagery*		High-Flight Imagery	
Imagery	Minutes	Imagery	Minutes
Pan 58	8.28	FRSL	7.33
FRSL	8.39	IR Ektachrome	9.00
IR 89B	8.50	Pan 25A	9.33
Pan 25A	9.72	IR 89B	9.61
Philco-Ford	12.61	Philco-Ford	9.62
IR Ektachrome	13.78	Pan 58	10.17

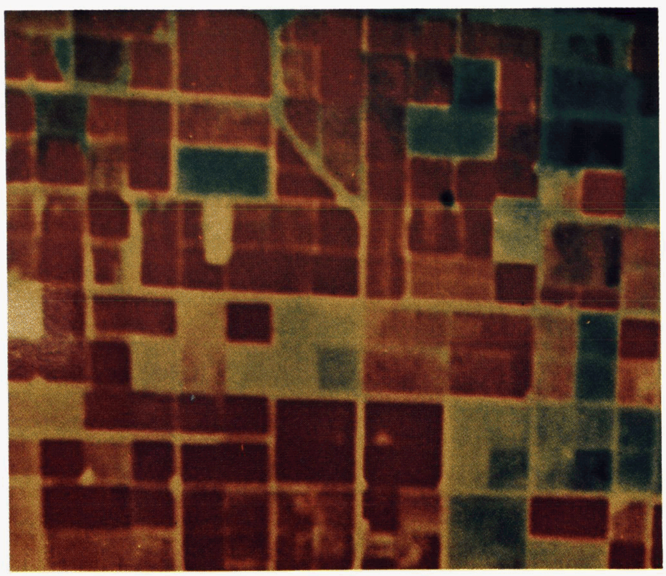
* Statistically significant differences in interpretability of image types were found for these tests.

The infrared Ektachrome test image also ranked consistently high in almost all categories, but did not rank as well as the FRSL optically combined imagery in interpretation time. This highlights the fact that "time required for interpretation", when used as a sole criterion, can be misleading. For example, imagery that is easily interpreted and imagery that is almost uninterpretable require less time for interpretation than images of intermediate quality.

The ability of infrared Ektachrome photography to cut through haze accounts for the consistently good spatial resolution, as shown in figures 4.3-11 and 4.3-12, when exposed either from aircraft or spacecraft. The Panchromatic 25A results did not rank as high as either the FRSL optical enhancement or the infrared Ektachrome.

THE BANDS USED AND THE CORRESPONDING FILTERS ARE AS FOLLOWS: PANCHROMATIC 25A PROJECTED THROUGH A WRATTEN 61 (GREEN) FILTER AND INFRARED 89B PROJECTED THROUGH A WRATTEN 25A (RED) FILTER. THE PANCHROMATIC 58 BAND WAS NOT USED DUE TO THE NEGLIGIBLE VALUE OF ITS POOR SPATIAL RESOLUTION.

Figure 4.3-6 FRSL Optical Combiner Two-Band Enhancement of S065 Apollo 9 Photography



THE BANDS USED AND THE CORRESPONDING FILTERS ARE AS FOLLOWS: PANCHROMATIC 25A PROJECTED THROUGH A WRATTEN 61 (GREEN) FILTER, INFRARED 89B PROJECTED THROUGH A 25A (RED) FILTER, AND PANCHROMATIC 58 PROJECTED THROUGH A WRATTEN 65A (CYAN) FILTER.

Figure 4.3-7 FRSL Optical Combiner Three-Band Enhancement of the High-Altitude Photography

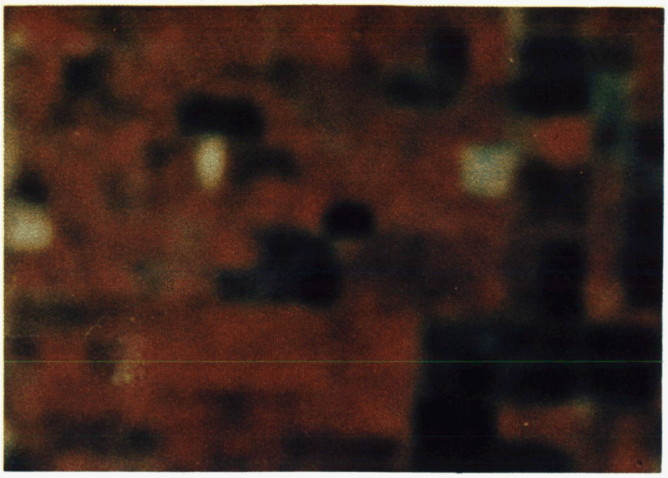
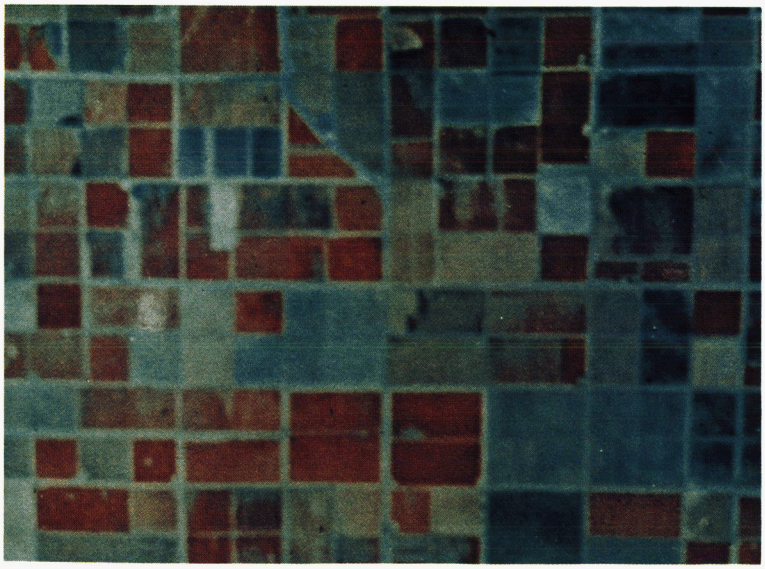
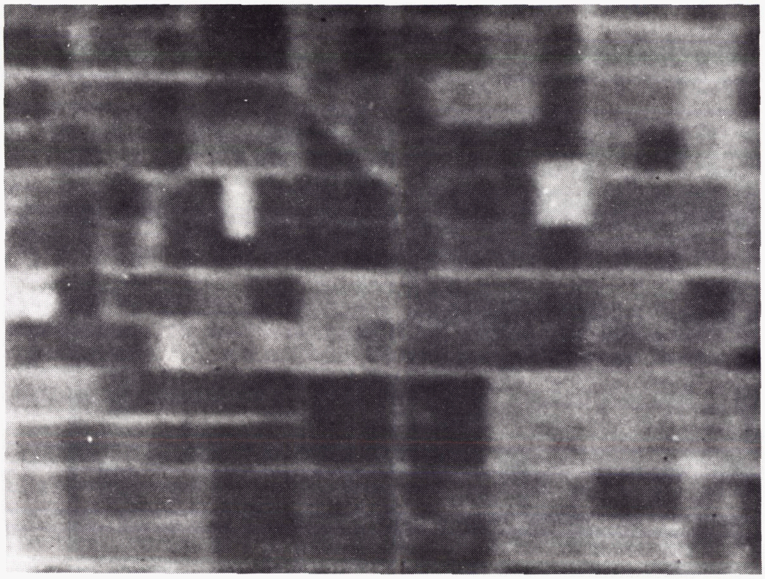


Figure 4.3-8 Infrared Ektachrome S065 Photography



THE INFRARED EKTACHROME PHOTOGRAPHS WERE NEAR THE TOP CONSISTENTLY ON ALL OF THE OVERALL RANKINGS.

Figure 4.3-9 Infrared Ektachrome High-Altitude Photography



THIS FILM WAS EXPOSED FOR ONLY THE RED WAVELENGTHS OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-10 Black-and-White Panchromatic S065 Photograph Taken from Space with a Wratten 25A Filter

For some crop categories the Philco-Ford electronic enhancements, figures 4.3-13 and 4.3-14, ranked high, but generally ranked near the bottom. Image enhancements obtained by means of the Philco-Ford electronic viewer ranked highest in the identification of bare soil from S065 imagery. This method simplifies the role of the interpreter by using bright colors to enhance often subtle tonal variations, and better results could be obtained if the enhancements were prepared with the intent of enhancing only one category at a time. The enhancements shown in figures 4.3-13 and 4.3-14 were made for the purpose of determining the optimum enhancement for all categories found in one image.

THIS FILM WAS EXPOSED FOR ONLY THE REFLECTIVE INFRARED WAVELENGTHS OF THE ELECTROMAGNETIC SPECTRUM

Figure 4.3-11 Black-and-White Infrared S065 Photograph Taken with a Wratten 89B Filter

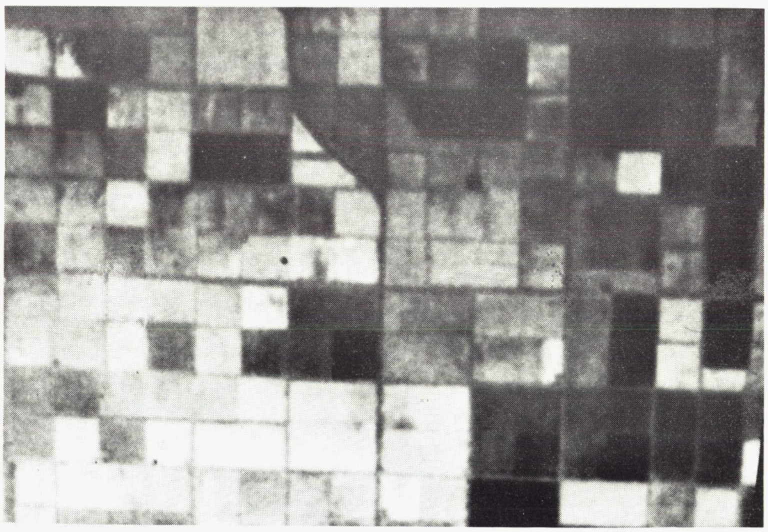


Figure 4.3-12 Black-and-White Infrared High-Altitude Photograph Taken with a Wratten 89B Filter

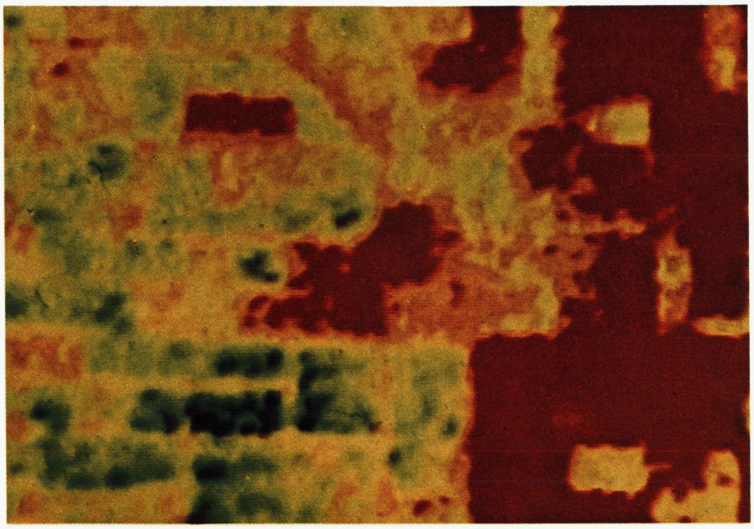


Figure 4.3-13 Philco-Ford Electronic Enhancement of the S065 Imagery Using Two Bands in Concert: Panchromatic 25A and Infrared 89B

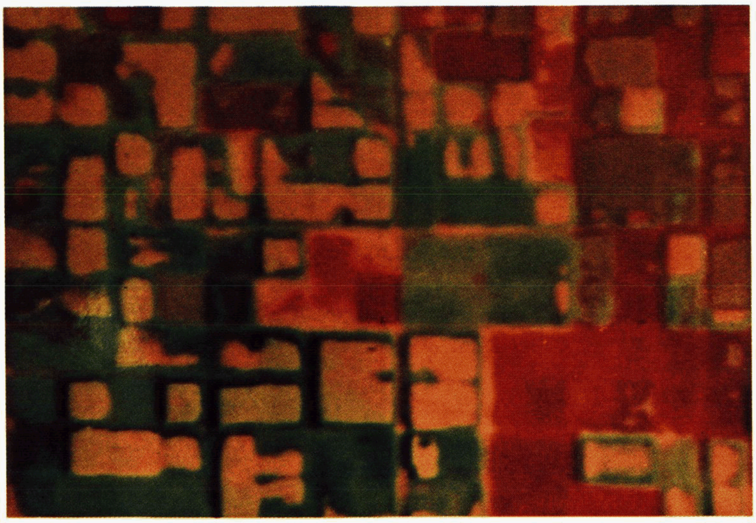


Figure 4.3-14 Philco-Ford Electronic Enhancement of the High-Flight Imagery Using Two Bands in Concert: Panchromatic 25A and Infrared 89B

Panchromatic 58 photography ranked at the bottom of all composite results except for the time criterion, table 4.3-4, where the image quality was so poor that many of the interpreters examined it very quickly. Results for the individual categories can be seen in tables 4.3-4 and 4.3-5. Panchromatic 58 definitely shows the least promise for photography from orbital altitudes since the tone contrast between significant features and spatial resolution is poor due to the scattering of the shorter (green) wavelengths by the earth's atmosphere.

12.0 COMPARISON OF THE S065 APOLLO IMAGERY AND THE HIGH-FLIGHT IMAGERY

Paragraphs 12.1 through 12.3 attempt to compare the photo-interpretation results from the S065 Apollo imagery with those of the "high-flight" imagery to determine if the reduction in spatial resolution in the space photography affects its usefulness for crop identification. The first comparisons are based on the overall results for all categories and all images. The second two comparisons are based on the results of the FRSL enhancements and the infrared Ektachrome images, which were arbitrarily chosen because they seemed to provide the optimum imagery on an overall basis.

The results of the ratings just presented indicate that there is very little difference in interpretability between the S065 Apollo imagery and the "high-flight" imagery for the particular features studied. The lack of statistically significant differences is probably due to the fact that tonal differences are somewhat more important than spatial resolution characteristics for the identification of crop types and field patterns.

At the present time, interpretation accuracy, on a percentage basis, is not exceptionally high. The highest "percentage correct" based on all categories is only 52.25 percent. It is important to realize, however, that all of these interpretation tests were carried out using third and fourth generation photography obtained at only one point in time during the growing season of these crops. A higher percentage of correct discriminations could be made if sequential photography were utilized.

TABLE 4.3-4

INTERPRETATION RESULTS OBTAINED USING
PAN 58 - S065 APOLLO PHOTOGRAPHY

Ranking	Category					
	Bare Soil	Alfalfa	Barley	Sugar Beets	Rye	Overall
Percent Correct	54.44	16.66	46.23	16.67	20.00	26.59
Ranking out of 6	6	6	5	5	3	6
Percent Commission	52.38	62.10	59.07	95.45	94.54	67.01
Ranking out of 6	6	6	5	6	6	5
Time/Min.	4.00	8.00	6.00	8.66	10.00	13.00
Ranking out of 6	2	2	2	3	6	1

TABLE 4.3-5

INTERPRETATION RESULTS OBTAINED USING
PAN 58 - HIGH-FLIGHT PHOTOGRAPHY

Ranking	Category					
	Bare Soil	Alfalfa	Barley	Sugar Beets	Rye	Overall
Percent Correct	74.76	21.87	34.87	66.66	0.	28.01
Ranking out of 6	5	4	6	2	6	6
Percent Commission	33.63	78.88	64.66	81.49	100.00	71.98
Ranking out of 6	5	5	6	2	6	6
Time/Min.	7.00	9.33	9.67	8.33	4.33	22.33
Ranking out of 6	5	2	5	4	2	6

At a given point in time many crops may have almost identical spectral signatures, but if viewed at a later date, differential phenological changes result in different spectral signatures providing valuable information to aid the interpreter in making correct identifications

12.1 Comparison of S065 Apollo and High-Flight Imagery for Aggregate of All Categories and All Images

Percentage Correct

S065 Apollo Imagery	High-Flight Imagery
41.28%	46.34%

Standard deviation = 2.79%

$$\text{t-value} = \frac{5.06}{2.79} = 1.81,\ t\left(\overset{\text{d.f.}}{140} \atop \underset{\text{level of significance}}{0.10}\right) = \pm 1.65$$

Significant difference at 10% level

Percentage Commission Errors

S065 Apollo Imagery	High-Flight Imagery
58.69%	60.27%

Standard deviation = 1.73

$$\text{t-value} = \frac{-1.58}{1.73} = 0.91$$

No significant difference

Time: Average Number of Minutes Per Image

S065 Apollo Imagery	High-Flight Imagery
10.21 min	9.19 min

Standard deviation = 0.68 min.

$$\text{t-value} = \frac{-1.02}{0.68} = 1.50$$

No significant difference

12.2 Comparison of S065 Apollo and High-Flight Imagery for an Aggregate of All Categories Using Only the FRSL Enhancements Which Seem to Provide One of the Two Best Types of Imagery Obtainable From Both the S065 and High-Flight Photography

Percentage Correct

S065 Apollo Imagery	High-Flight Imagery
46.17% Correct	39.47% Correct

Standard deviation = 11.33%

t-value $= \frac{-6.73}{11.33} = -0.59$, $t\left({}^{34}_{0.10}\right) = \pm\ 1.69$

No significant difference

Percentage Commission Errors

S065 Apollo Imagery	High-Flight Imagery
57.19%	55.80%

Standard deviation = 10.82%

t-value $= \frac{-1.40}{10.82} = 0.12$

No significant difference

Time: Average Time Per Image in Minutes

S065 Apollo Imagery	High-Flight Imagery
8.39 min	7.33 min

Standard deviation = 1.88%

t-value $= \frac{-1.05}{1.88} = -0.55$

No significant difference

12.3 Comparison of S065 Apollo and High-Flight Imagery Aggregate Ratings Based on All Categories But Using Only the Infrared Ektachrome Which Seems to be One of the Two Best Types of Imagery Obtainable From Both the S065 and High-Flight Photography

Percentage Correct

S065 Apollo Imagery	High-Flight Imagery
46.17%	52.25%

Standard deviation = 8.4%

$$\text{t-value} = \frac{-6.08}{8.47} = -0.71\ ,\quad t\,\binom{34}{0.10} = \pm\ 1.69$$

No significant difference

Percentage Commision Errors

S065 Apollo Imagery	High-Flight Imagery
49.27%	50.16%

Standard deviation = 9.08%

$$\text{t-value} = \frac{0.90}{9.08} = 0.10$$

No significant difference

Time: Average Interpretation Time Required Per Image

S065 Apollo Imagery	High-Flight Imagery
13.78 min	9.00 min

Standard deviation = 2.70 minutes

$$\text{t-value} = \frac{4.77}{2.70} = 1.76$$

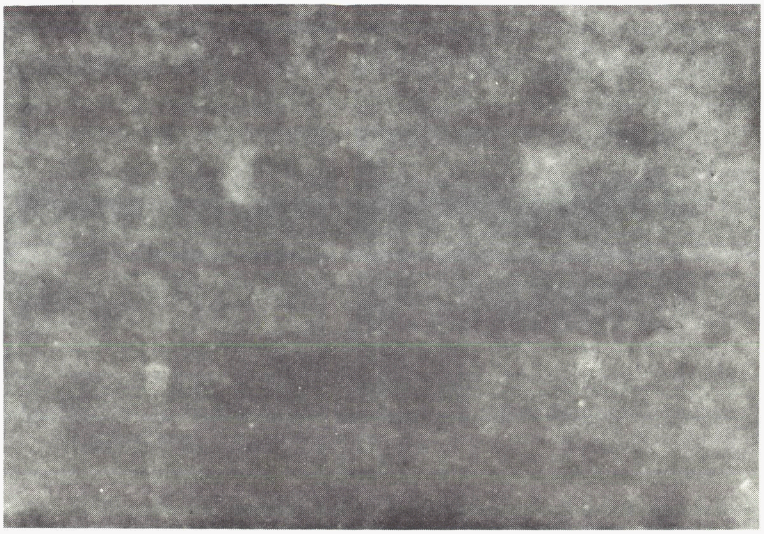
Significant difference at 10% level

13.0 CONCLUSION

As a result of this study, it seems feasible that certain crop types and field conditions can be inventoried by means of photographs taken at orbital altitudes. However, sequential orbital photography should be used to achieve the accuracy required by many users of such data. Owing to the inherent phenological changes that take place in vegetation, a comparative analysis should significantly improve interpretation accuracy.

The two best image types for crop inventories appear to be the FRSL optical enhancement and the Ekta-Aero infrared (infrared Ektachrome) imagery techniques. The FRSL imagery technique, while somewhat poorer in spatial resolution than the infrared Ektachrome, produces better color contrasts among crops. Panchromatic 25A (sensitive to the red portion of the electromagnetic spectrum) and infrared 89B (sensitive to the reflective infrared portion) give more information than the third black-and-white band (Panchromatic 58) that was used in these tests. (See figures 4.3-15 and 4.3-16.) The Panchromatic 25A and infrared 89B bands provide the most valuable input for both the optical and electronic enhancement systems. The Panchromatic 58 (sensitive to the green portion of the electromagnetic spectrum) gives, by far, the least information, especially from orbital altitudes where, due to the relatively greater scattering of the green wavelengths by the earth's atmosphere, very poor spatial resolution is obtained.

Electronic enhancement systems such as the Philco-Ford video image enhancement and the University of Kansas IDECS, figures 4.3-13, -14, -17, and -18, show promise of improvement in the interpretation of photographs of the earth taken at orbital altitudes. However, more research must be carried out to determine if these techniques can produce results comparable to those obtained by using multiband optical enhancements.



EXPOSED FOR ONLY THE GREEN WAVELENGTHS OF THE ELECTROMAGNETIC SPECTRUM.

Figure 4.3-15 Black-and-White Panchromatic S065 Photograph Taken with a Wratten 58 Filter

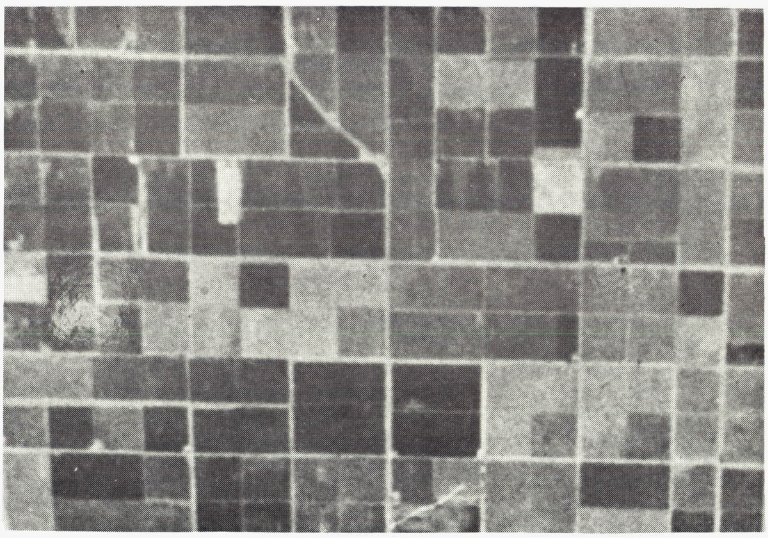


Figure 4.3-16 Black-and-White Panchromatic High-Altitude Photograph Taken with a Wratten 58 Filter

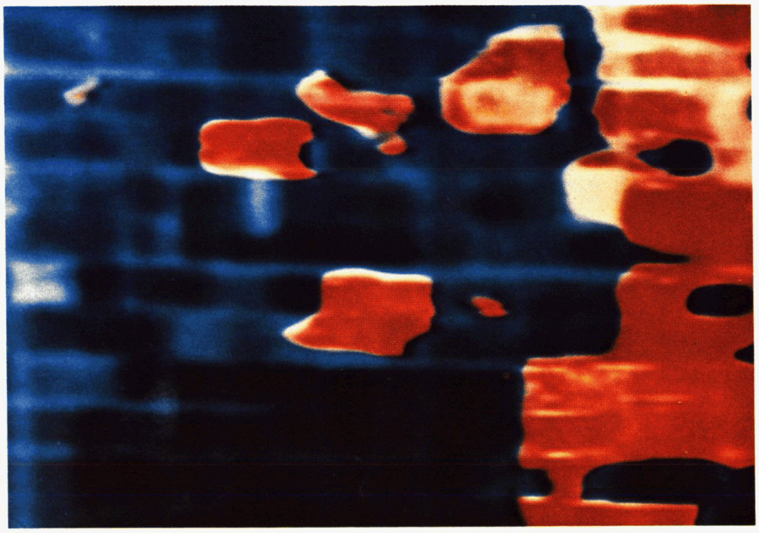


Figure 4.3-17 IDECS S065 Electronic Enhancement for Bare Soil (red) Using Three Bands in Concert: Panchromatic 25A, Panchromatic 58, and Infrared 89B.

Figure 4.3-18 IDECS High-Flight Electronic Enhancement for Rye (yellow) and Barley (orange) Using Three Bands in Concert: Panchromatic 25A, Panchromatic 58 and Infrared 89B.

14.0 SUMMARY AND CONCLUSIONS

The following is a description of the types of photographs that were obtained:

a. Space photographs from the Apollo 9 mission

b. Photographs taken on concurrent flights made over the same NASA test sites by support aircraft

c. Photographs taken on subsequent "high-flights" designed to obtain simulated sequential space photographs

From the studies of the Apollo 9 photography, and the supporting "high-flight" photography that was obtained concurrently and on subsequent dates (roughly one-month intervals), the following is concluded:

a. Although the nominal resolution of the Apollo 9 photography is only about 300 to 400 feet, based on low-contrast targets, features such as roads and canals, having a minimum dimension of only 20 to 30 feet, are clearly discernable.

b. The nominal resolution of the supporting 35 mm "high-flight" photography is approximately one order of magnitude better than that obtained on the Apollo 9 mission.

c. The accurate discrimination of some important earth resource features (forest vs agricultural lands or vegetation vs bare soil) is possible even with black-and-white space photographs.

d. Additional earth resource features are identifiable on infrared Ektachrome space photographs (bottom hardwood stands and individual crop types).

e. The interpretability of some of these features is still further increased through the use of optical or electronic equipment to form color composite images from two or more wavelength bands of black-and-white photography.

f. Despite higher spatial resolution, "high-flight" photographs taken with the same film-filter combinations provided very little improvement in interpretability of specific earth resource features. These features were subjected to the quantitative evaluation test described in item g.

g. Detailed studies were made in several geographic areas in order to arrive at a quantitative determination of the interpretability of Apollo 9 photographs and associated "high-flight" photography. In these tests the photography was studied in its original state (either as opaque prints or as positive transparencies) and after being electronically or optically enhanced by various techniques. One study dealt with agricultural crops near Phoenix, Arizona and also in the Imperial Valley of California. These quantitative studies led to the following conclusions:

1. Accuracy in the identity of crop types and field conditions rarely exceeded 60% when the photo interpreters analyzed only photographs obtained during the March 1969 Apollo 9 mission. This was a less-than-optimum time of the year for this purpose. Those who wish to use this kind of agricultural information require an order of accuracy of 90 to 95 percent.

2. If the photo interpreters were given access to the "high-flight" photography taken concurrently with the Apollo 9 photographs, but at much higher spatial resolution, the quantitative data showed no statistically significant improvement in image interpretablility for the particular earth resource features under investigation. However, when sequential "high-flight" photography taken at later dates was used, the accuracy was substantially improved.

3. On both the space photography and the "high-flight" photography, infrared Ektachrome was significantly more interpretable than any of the matching frames of multiband black-and-white photography.

4. When the matching frames of black-and-white photography were combined and enhanced, either optically or electronically, interpretability was improved to the point where the derived information was roughly equivalent to (but only rarely better) than obtained from the infrared Ektachrome photography. It should be emphasized, however, that the studies to date on this particular project have not permitted adequate investigation of the full possibilities of multiband image enhancement. Primarily because of time limitations, the enhancements studied thus far were those which were made with a view to improving the overall interpretability of the multiband black-and-white photography, as indeed they did. The next step will be that of using optical and electronic image enhancements of this multiband black-and-white photography to make an entire series of color enhancements. One enhancement will be designed to distinguish one earth resource feature from everything else, and a second enchancement to distinguish a second earth resource feature from everything else, etc. Some of the earlier studies, dealing only with aerial photography, have shown that such a series of enhancements is superior to those provided by infrared Ektachrome photography.

5. In any operational system designed to exploit the broad synoptic view of space photography, it would be highly desirable to achieve high spatial resolution over the entire frame instead of merely on small sections of it. Before this could be done, however, an optical combiner providing a better means for registration than the one available to us would have to be developed for electronic combiners. To further improve the resolution of the electronic combiners, the number of raster lines would have to be increased.

h. A system for classifying range resources on space photography, or for classifying timber stands and other land use classes, can greatly improve the efficiency of a multistage sampling system that is based on photography, aerial photography and field observation. Quantitative tests show that photo interpreters could achieve an accuracy of 80 to 90 percent in making such stratifications from Apollo 9 photography. Maximum use of the "convergence of evidence principle" can further improve the accuracy and usefulness of stratifications made from an interpretation of space photography.

i. The various kinds of earth resources studied in this report correspond quite closely to the informational requirements of those who seek to manage earth resources. Our findings appear to be not only of scientific interest, but also of great practical importance.

j. On the one hand, there are strong proponents for using aircraft rather than spacecraft for making the earth resource surveys and, on the other hand, those who advocate using spacecraft rather than aircraft. Our findings, for the most part, support a third view. That is, operational earth resource surveys of the future might best be made by means of a multistage sampling technique employing spacecraft, aircraft and ground observations.

k. Because of the importance of obtaining sequential photographic coverage to aid in the inventoring of earth resources from aerial and space photography, and because cloud cover makes very difficult the obtaining of sequential coverage in many geographic areas of interest, we must reiterate one important conclusion of our earlier reports: Cloud cover is likely to be the most serious deterrent when making photographic resource surveys from either aircraft or spacecraft.

SECTION 4.4

USE OF ENHANCEMENT EQUIPMENT
ON
AERIAL PHOTOGRAPHY OF GARDEN AND BUSH KEYS
IN THE DRY TORTUGAS
FLORIDA

Dr. Howard J. Teas
University of Miami
Coral Gables, Florida
1970

SECTION 4.4

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

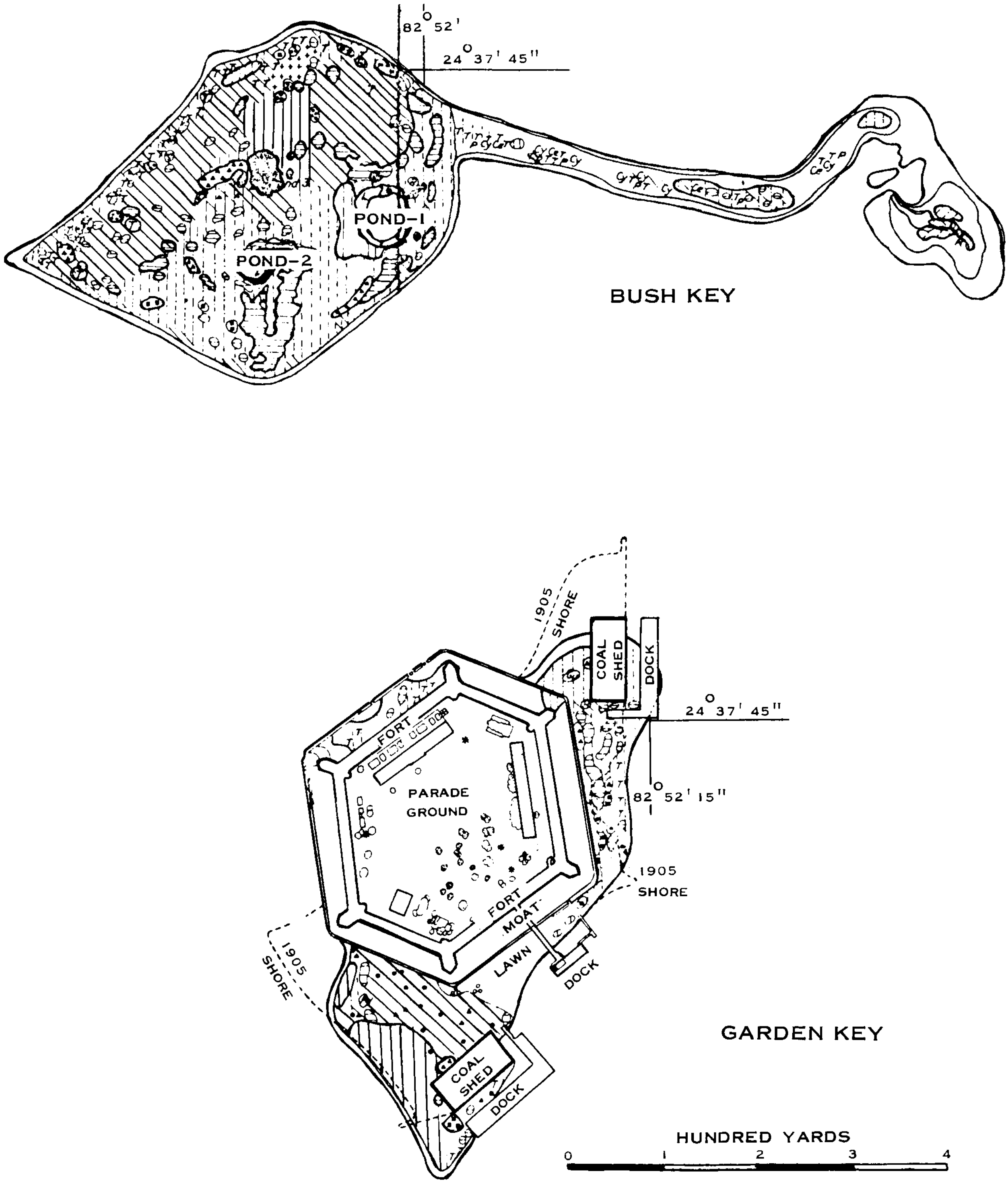
The purpose of this study, headed by Dr. H. J. Teas, Department of Biology, University of Florida at Coral Gables, Florida, was to determine the feasibility of using image enhancement equipment to analyze vegetation. The area chosen for this evaluation was at Garden and Bush Keys in the Dry Tortugas island group.

The Dry Tortugas are a group of low-lying islands about 70 miles west of Key West, Florida, and are accessible only by boat or seaplane. The present level of ground truth notes, drawings, ground level and aerial photographs of the Dry Tortugas area is quite detailed. However, this report is concerned primarily with ground truth developed on two trips to Garden and Bush Keys, in 1969 and 1970, by Dr. H. J. Teas, Dr. J. H. Davis and teams of advanced ecology graduate students. Figure 4.4-1 shows some of the detail in Garden and Bush Keys.

2.0 GARDEN KEY

Garden Key, which is primarily Fort Jefferson National Manument, is approximately 350 by 500 yards. The species of the larger shrubs and trees within the walls of the fort are as follows:

Symbol	Scientific Name	Common Name
B	Bursera simaruba	Gumbo-limbo
BW	Conocarpus erecta	Buttonwood
BW_s	C. erecta var. sercea	Silver buttonwood
Ca	Cactus sp.	Cactus
Cs	Cassia sp.	--
*	Cocos nucifera	Coconut palm
Gu	Psidium guajava	Guava
Hy	Hymenocallis keyensis	Spider lily
G	Cordia sebestena	Geiger tree
Oc	Ochrosia elliptica	--
Ol	Nerium oleander	Oleander



(J.H. DAVIS - 1942)

Figure 4.4-1 Bush and Garden Keys, Florida

Pc	Phoenix canariensis	Date palm
Pd	P. dactylifera	Date palm
Sn	Schinus teribinthifolius	Brasilian pepper-bush
Sg	Cocolobis uvifera	Seagrape
Ta	Tamarindus indicus	Tamarind
Te	Terminalis catappa	Indian almond
Th	Thespesia populnea	--
W	Washingtonia filifera	Washington palm

The plants visible in the aerial photograph are shown in figure 4.4-2 and are identified in figure 4.4-3. An image enhancement photograph of this area, as seen on the Philco-Ford electronic enhancement viewer, is shown in figure 4.4.-4.

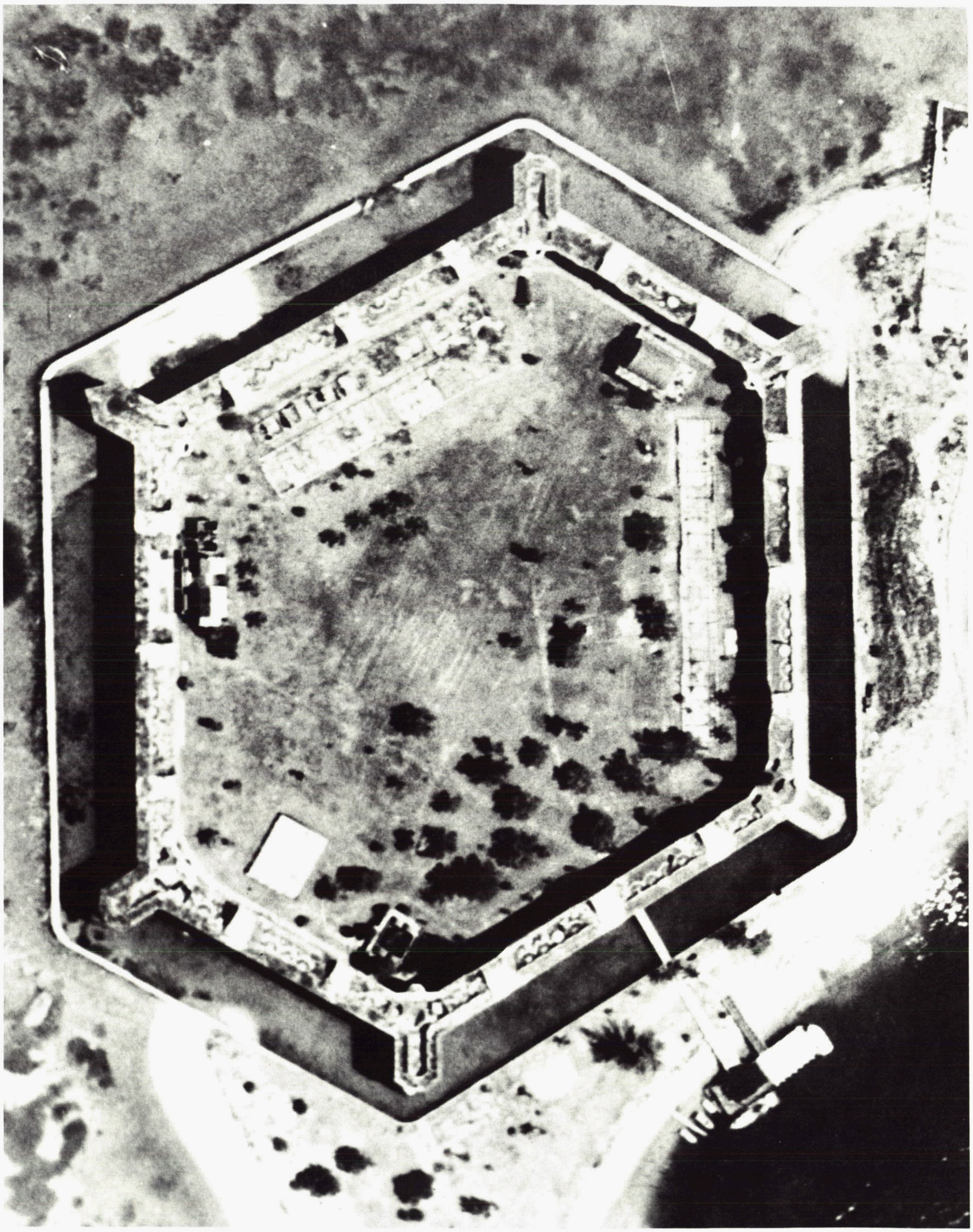
Although not necessarily visible in figure 4.4-4, the following trees and shrubs could be distinguished on the video display:

silver buttonwood
buttonwood
gumbo-limbo
date palm
coconut palm

With a more diverse selection of wavelengths, more species could probably be seen.

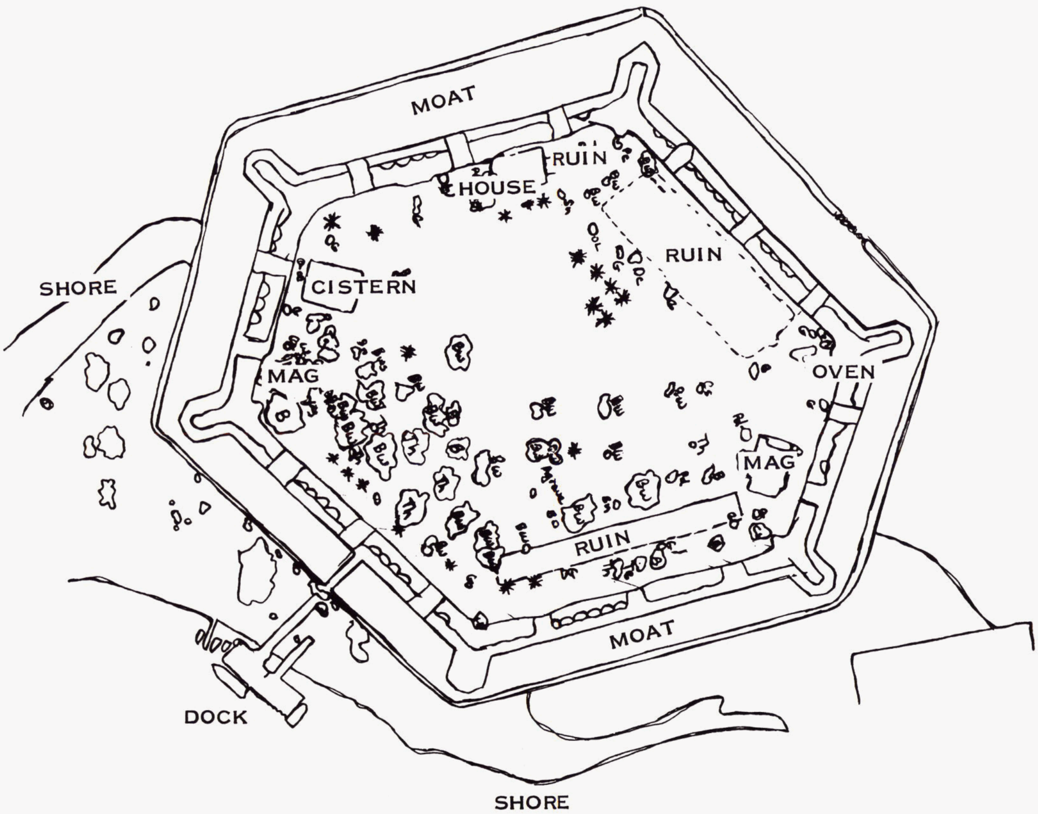
3.0 BUSH KEY

Bush Key is located about 250 yards east of Garden Key and covers an area approximately 300 by 1100 yards. It has a number of species and associations of species, the most prominent of which are shown in figure 4.4-5. All of these groups can be distinguished by manipulation of the Philco-Ford viewer. They cannot, as yet, be distinguished by "blind programmed analysis." An aerial photograph and image enhanced photograph of a portion of this area as seen on the Philco-Ford viewer are shown in figure 4.4-6.



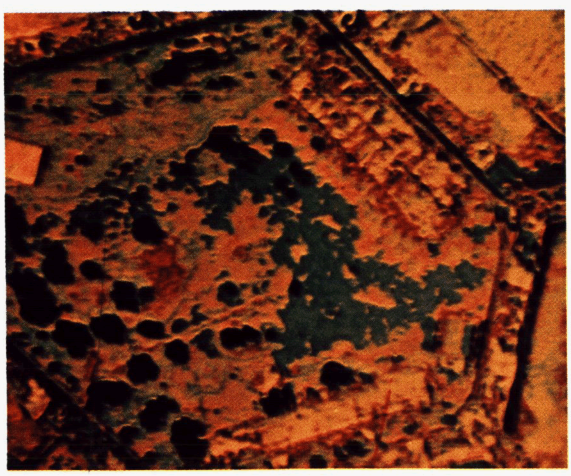
EKTACHROME SUPER XX AEROGRAPHIC FILM
K-2 CAMERA AT 1500 FEET, 27 AUGUST 1969

Figure 4.4-2 Fort Jefferson, Garden Key, Florida



VEGETATION ANALYSIS

Figure 4.4-3 Fort Jefferson, Garden Key, Florida



KODACHROME OF VIDEO DISPLAY ON PHILCO-FORD IMAGE ENHANCEMENT CONSOLE

Figure 4.4-4 Fort Jefferson, Garden Key, Florida

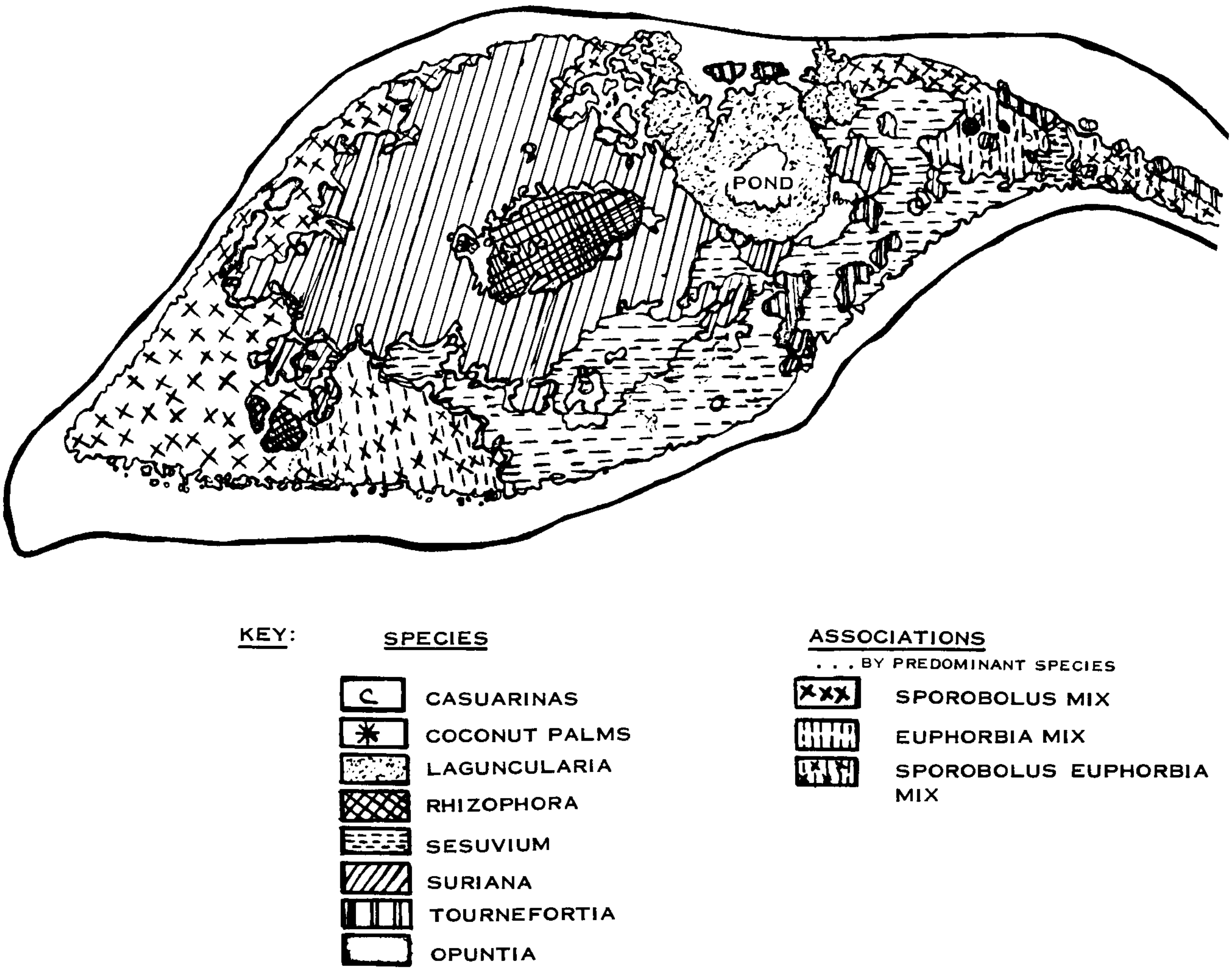
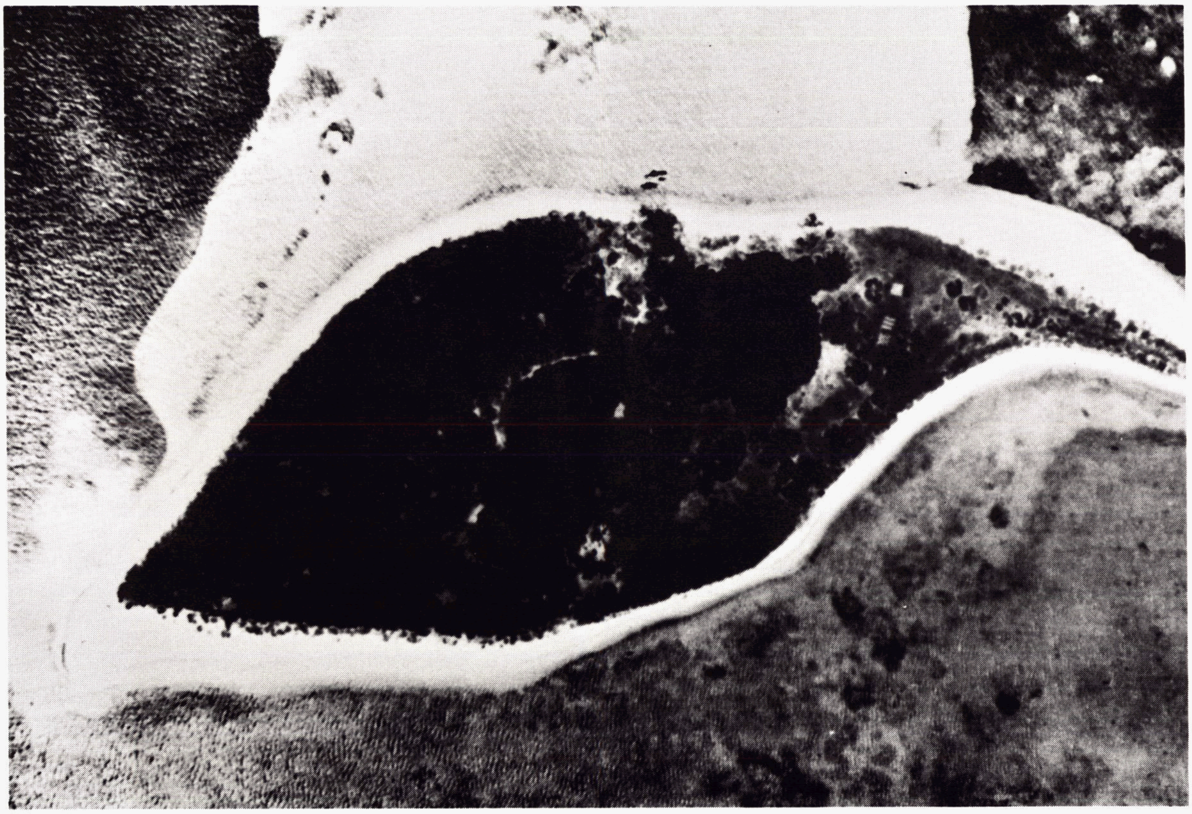
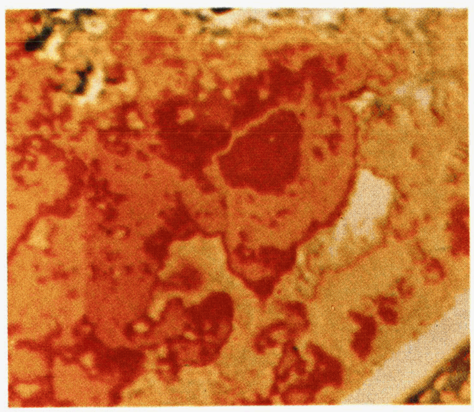


Figure 4.4-5 Ground Truth, Bush Key, Florida



PHOTOGRAPH OF BUSH KEY, FLORIDA



KODACHROME OF VIDEO DISPLAY ON PHILCO-FORD IMAGE ENHANCEMENT CONSOLE

Figure 4.4-6 Bush Key, Florida

4.0 CONCLUSIONS

The electronic image enhancement technique shows considerable promise in the analysis of vegetation, as shown in this study of the Florida keys.

SECTION 4.5

GEOLOGICAL STUDIES OF YELLOWSTONE NATIONAL PARK IMAGERY USING AN ELECTRONIC IMAGE ENHANCEMENT SYSTEM

Harry W. Smedes
US Department of the Interior
Geological Survey

SECTION 4.5

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

1.0 INTRODUCTION

This study describes the type of image enhancement system used, the kinds of image enhancement obtained, the results obtained from various kinds of remote-sensing imagery (black-and-white multiband, color, color infrared, thermal infrared, and side-looking K-band radar) of areas in Yellowstone National Park, and additional fields for the application of these techniques.

The study was conducted by Mr. H. W. Smedes, Chief Investigator for the US Department of Interior, Coast and Geological Survey, with the support of Mr. E. Ruple of the Denver, Colorado office, and Mr. D. Tatlock and Mr. G. Greene associated with the Menlo Park, California office.

2.0 DESCRIPTION OF THE PROCESSING SYSTEM

Transparencies consisting of pairs of color-separation negatives, black-and-white multiband photographs, or single black-and-white images were used in the system.

Color separation negatives were made from color prints of transparencies by successively photographing the color print on black-and-white film using red, green, and blue filters. The three separation negatives collectively contain all the color information contained in the original color image.

Black-and-white multiband photograph transparencies were made by photographing the natural terrain with a 9-lens system aerial camera. Each lens is filtered to receive light from restricted parts of the spectrum from violet to near-infrared. The nine images that are obtained are analogous to nine different color-separation negatives.

3.0 ONE-BAND PROCESSING

3.1 Density Slicing

The 16-level quantizer displays zones of equal density range. By the proper selection of quantizer levels on single black-and-white photographic images, all or most areas of bare rock, talus, vegetated areas, or water can be delineated, because each material category has different and limited ranges of reflectance.

The adjacent edges of the density ranges produce isodensity contours. Therefore, the thermal infrared images can be transformed into thermal contour displays (figures 4.5-1 and 4.5-2). Combined with ground information and other thermal control, these images become quantitative thermal maps. Enhanced single images are shown in figure 4.5-8A, where surficial deposits, timber, and grasslands are contrasted with hot spring deposits and landslides. Similar processing of other images can yield quantitative control data on depths of water bodies.

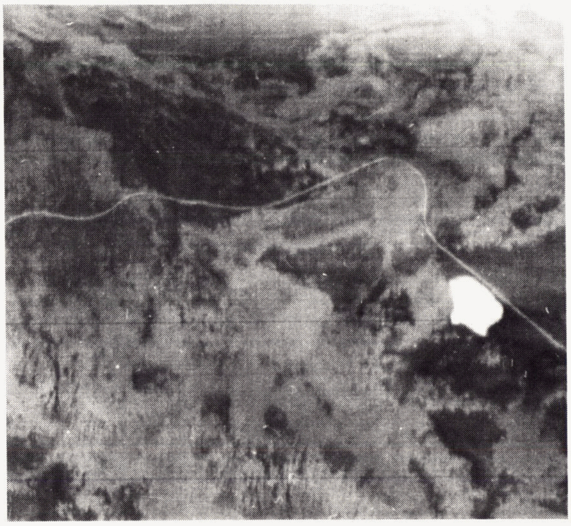
3.2 Enhancing Different Parts of the Density Curve

If the position and width of the 16-level quantizer is shifted, various density contrasts can be emphasized. Subtle differences in the least dense regions of the scene can be enhanced if the ramp is shifted toward the toe of the density curve. Denser regions can be enhanced by shifting toward the shoulder of the curve.

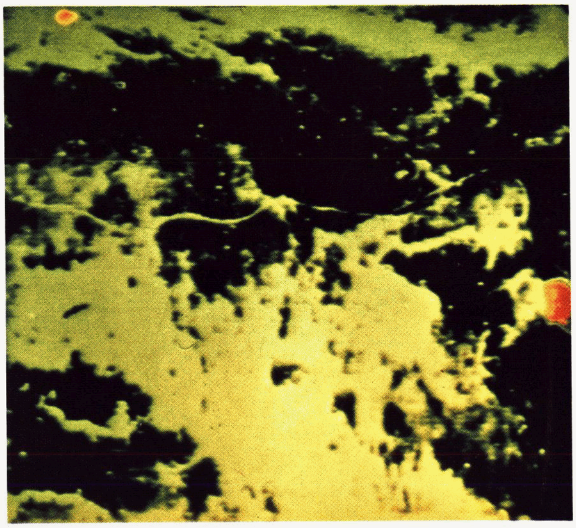
As shown in figure 4.5-3, the radar image was enhanced by this method to enhance the linear features of different trends.

4.0 TWO-BAND PROCESSING

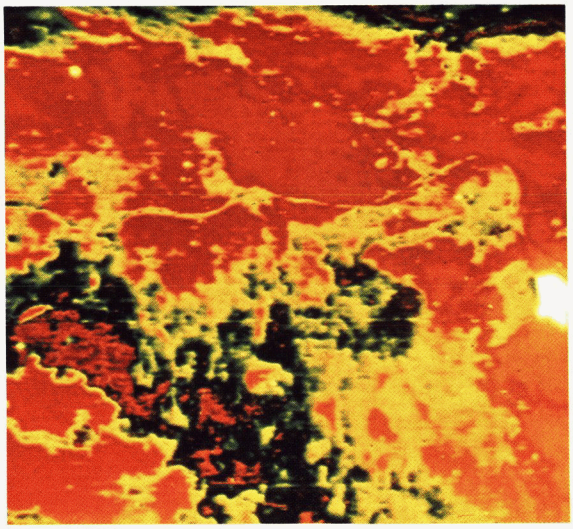
By electronically combining the signal from two images (four are contemplated in the future), additional kinds of processing can be performed, as shown in figures 4.5-4 through 4.5-8.



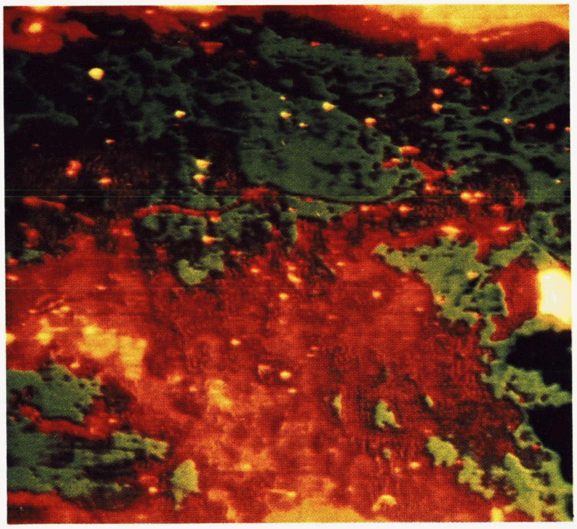
(A) THE 8-12 μM THERMAL INFRARED IMAGE WAS TAKEN AT 2 AM, MID-SEPTEMBER 1967. THE WARMEST OBJECT IN THE SCENE IS THE LAKE, WHICH APPEARS AS A LIGHT TONE CONTRASTING STRONGLY WITH ALL OTHER TONES ON THE IMAGE. A BLACKTOP ROAD, BEDROCK AND TALUS OF VOLCANIC ROCK, AND FORESTED AREAS ALL APPEAR AS MEDIUM GRAY TONES, AND MEADOWS APPEAR AS DARK TONES (COLDEST OBJECTS IN THE SCENE).



(B) THE FIRST COLOR DISPLAY PRESENTS THE LAKE AS ORANGE, ALL INTERMEDIATE TEMPERATURES AS GREEN, AND ALL COLD TEMPERATURES AS BLACK. THIS IS AN EXAMPLE OF CLARIFYING CATEGORIES BY DELETING TONE MOTTLING THAT CANCELS BROADER RELATIONS OF CATEGORIES (OR GENERALIZATIONS OF TONES).

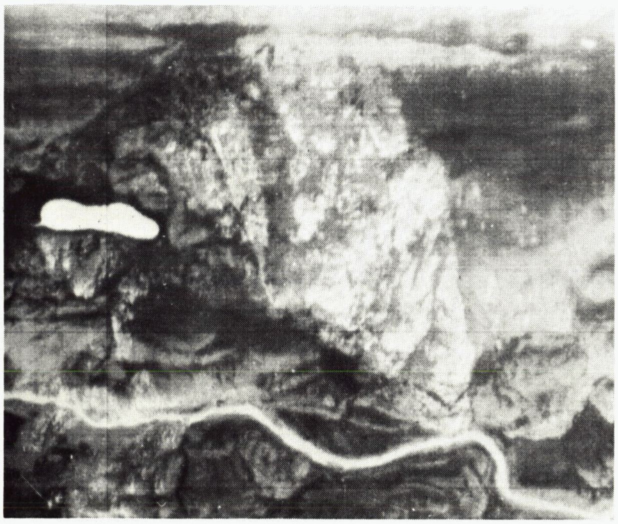


(C) IN ANOTHER DISPLAY OF THE SAME SCENE, THE OBJECTS OF INTERMEDIATE TEMPERATURE (TONE) ARE SUBDIVIDED INTO FOUR THERMAL SLICES, AND THE COLD MATERIALS INTO TWO, ALL DISTINCTLY BOUNDED IN CONTRAST TO THE HAZY ILL-DEFINED BOUNDARIES SHOWN IN THE ORIGINAL IMAGE (A).

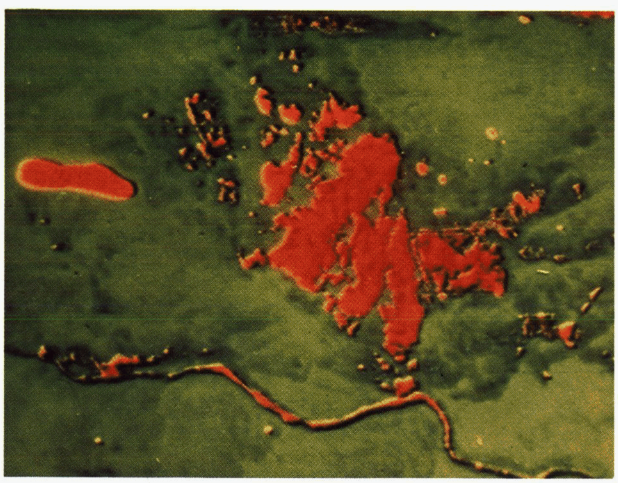


(D) IN THE LAST DISPLAY, A GREAT VARIETY OF DETAIL AND COLOR TONES ARE SHOWN SUBDIVIDING THE SCENE INTO SIX COLOR SLICES AS IN (C), EXCEPT THAT THE GREENS AND REDS ARE REVERSED, AND THE DARKER SCENE ELEMENTS (SHOWN AS GREEN) SHOW FAR GREATER DETAIL THAN IN (C), ALTHOUGH THERE IS LITTLE OR NO GEOLOGIC VALUE IN OBTAINING THIS DETAIL.

Figure 4.5-1 Thermal Infrared and Enhanced Images of Area Near Floating Island Lake, North-Central Yellowstone National Park



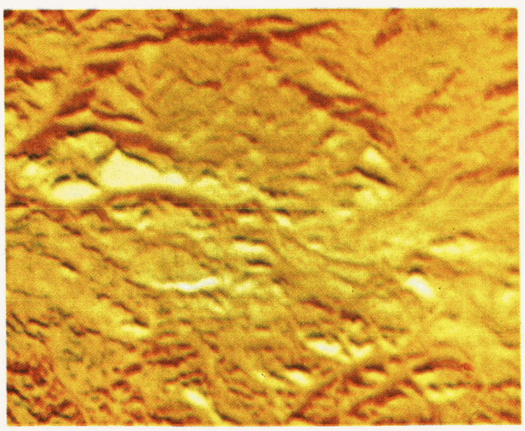
(A) THE 8-12 μM THERMAL INFRARED IMAGE WAS TAKEN AT 2 A.M. MID-SEPTEMBER 1967. THE WARMEST OBJECT IN THE SCENE IS A LAKE ON THE LEFT EDGE. THE YELLOWSTONE RIVER, LOWER EDGE, AND A LARGE MASS OF GRANITIC GNEISS, LEFT CENTER, ARE SHOWN AS AN INTERMEDIATE TEMPERATURE. GRASSLANDS ARE A DARKER GRAY, AND FORESTED AREAS ARE BLACK.



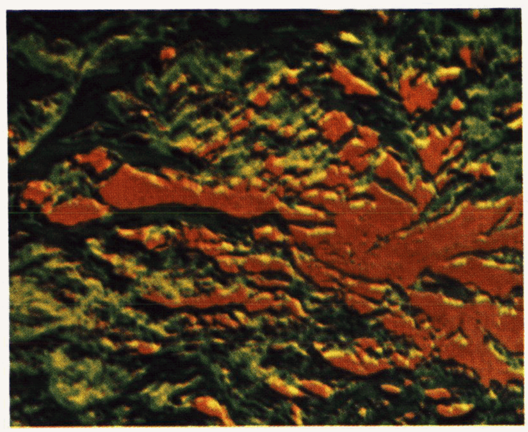
(B) IN THE PROCESSED IMAGE, THE LAKE, RIVER, AND ALL BEDROCK EXPOSURES (GRANITIC GNEISS) HAVE BEEN ENHANCED TO SHOW AS ORANGE, IN CONTRAST TO SOIL MEADOWS AND FOREST, WHICH SHOW AS GREEN. THIS IMAGE CONSTITUTES A "MAP" SHOWING DISTRIBUTION OF BEDROCK OUTCROPS.

Figure 4.5-2 Thermal Infrared and Enhanced Images of an Area West of the Buffalo Plateau, North-Central Yellowstone National Park

(A) THE RADAR IMAGE COVERS AN AREA ALONG THE YELLOWSTONE RIVER FROM THE MOUTH OF CREVICE CREEK EASTWARD TO THE MOUTH OF LAVA CREEK.

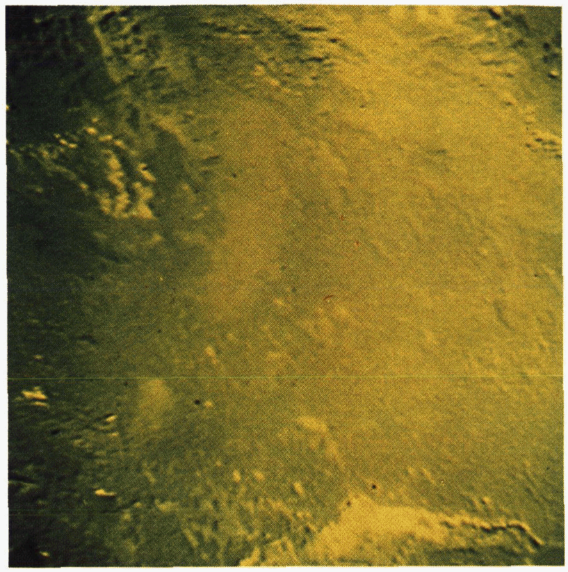


(B) THE NORTHWEST TREND LIGHT-COLORED LINEAMENTS ARE ENHANCED.



(C) THE NORTHEAST TREND DARK LINEAMENTS ARE ENHANCED. THE DARK AREAS OF RADAR SHADOW AND THE EXTENSIVE SURFACES OF LOW RELIEF IN THE CENTRAL AND EAST-CENTRAL PARTS ARE SHOWN AS RED IN CONTRAST TO THE AREAS OF HIGH RELIEF, SHOWN AS GREEN.

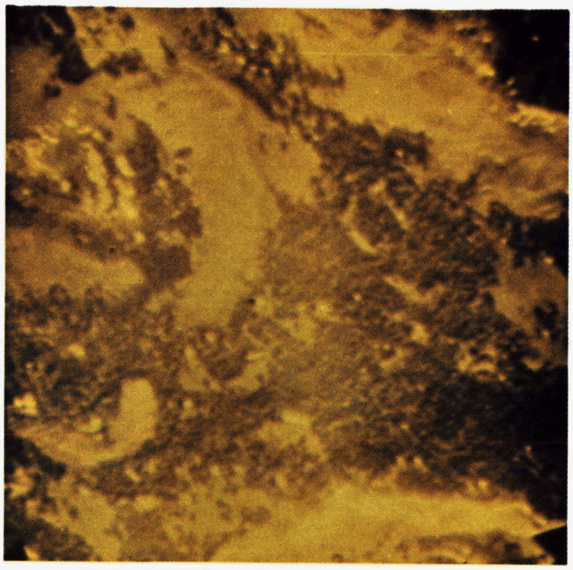
Figure 4.5-3 Side-Looking K-Band Radar Image and Enhanced Images of an Area in North-Central Yellowstone National Park (look direction is to the south)



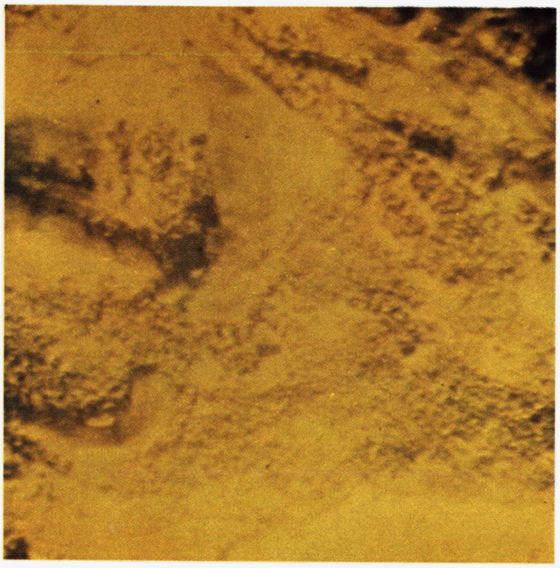
(A) POSITIVE OF FRAME 3 SUPERIMPOSED ON NEGATIVE OF FRAME 4. HIGH DEGREE OF REDUNDANCY IS INDICATED BY LOW CONTRAST.

(B) POSITIVE OF FRAME 3 SUPERIMPOSED ON NEGATIVE OF FRAME 9. LOW DEGREE OF REDUNDANCY IS SHOWN BY HIGH CONTRAST.

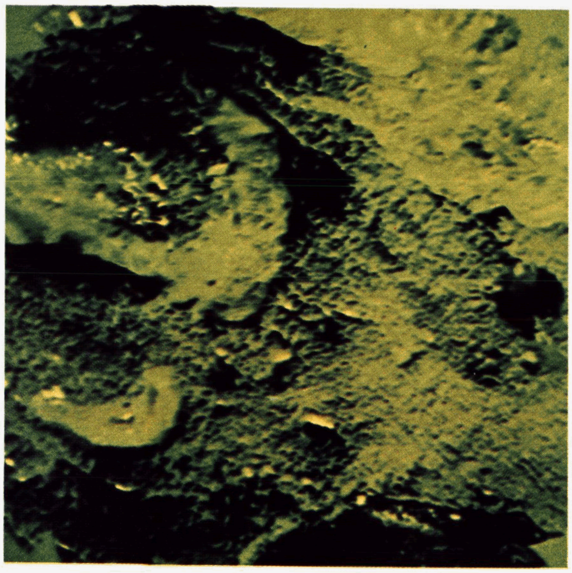
Figure 4.5-4 Example of Redundancy Test Multiband Photograph Images of an Area in the Southern Part of the Gallatin Range (See figures 4.5-5 and 4.5-7)



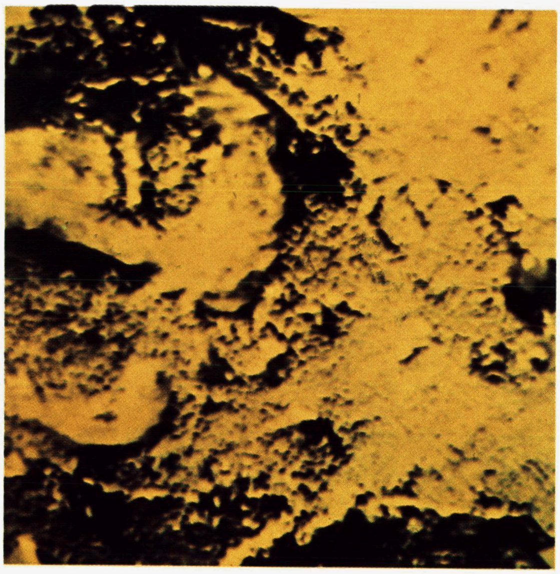
(A) VIDEO IMAGE OF FRAME 3.



(B) VIDEO IMAGE OF FRAME 9.

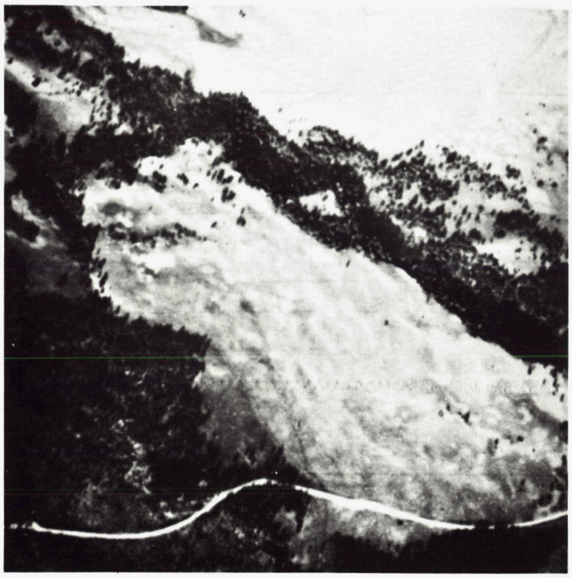


(C) POSITIVE OF FRAME 3 SUPERIMPOSED ON NEGATIVE OF FRAME 9, AS IN REDUNDANCY TEST (FIGURE 4.5-4B)

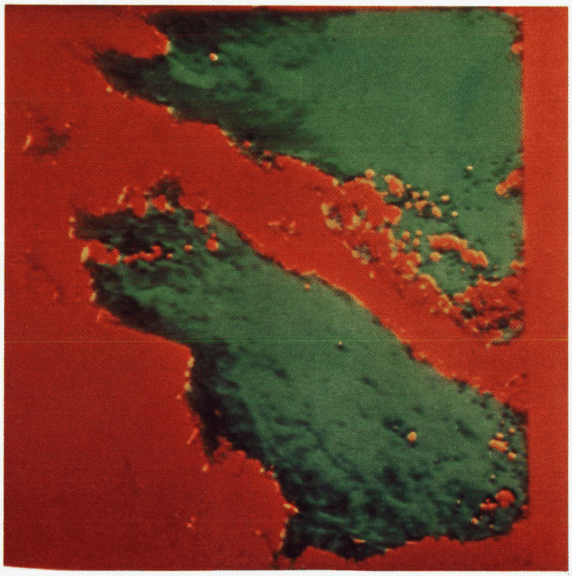


(D) SAME AS (C), BUT WITH IMAGES SLIGHTLY MISALIGNED TO ENHANCE EDGES.

Figure 4.5-5 Examples of Edge Enhancement by Positive/Negative Masking. Photographic Images from Multiband 9-Lens Camera of an Area in the Southern Part of the Gallatin Range (See figures 4.5-4 and 4.5-7)

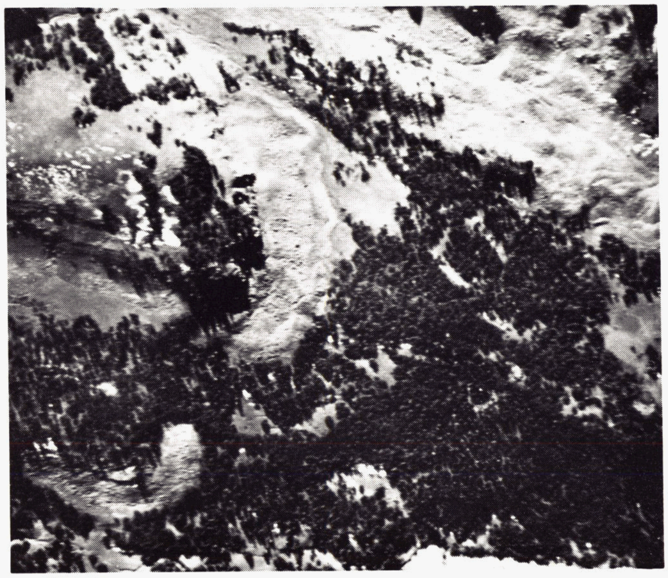


(A) PRINT FROM RED COLOR-SEPARATION NEGATIVE MADE FROM COLOR FILM, SHOWING MEADOWS ON KAME TERRACE DEPOSITS SURROUNDED BY FOREST. HIGHWAY FROM MAMMOTH TO TOWER JUNCTION IS SHOWN NEAR THE BOTTOM EDGE. THOUGH BOTH LARGE MEADOWS ARE ON KAME TERRACES (NOTE THE GREAT DIFFERENCE IN APPEARANCE), ONE IS MOTTLED AND THE OTHER IS RATHER UNIFORM.

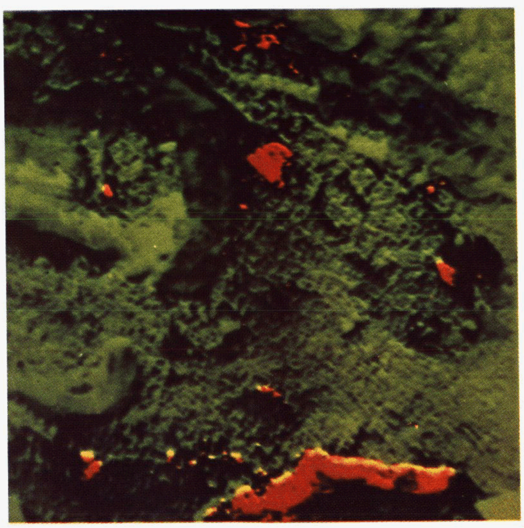


(B) ENHANCED IMAGE FROM THE RED AND GREEN COLOR-SEPARATION NEGATIVES SHOWING GENERALIZING OF TONE SUCH THAT BOTH MEADOWS APPEAR UNIFORM (GREEN) IN CONTRAST TO THE FOREST (RED).

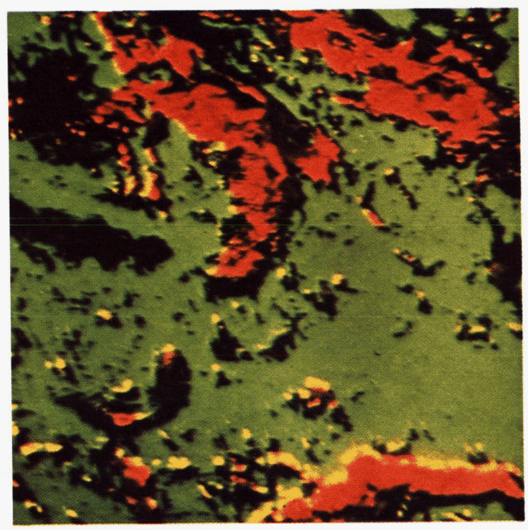
Figure 4.5-6 Print and Enhanced Image from Color Separation Negative of an Area West of Floating Island Lake, North-Central Yellowstone National Park



(A) PHOTOGRAPH FROM MULTIBAND 9-LENS CAMERA
(FRAME 5)



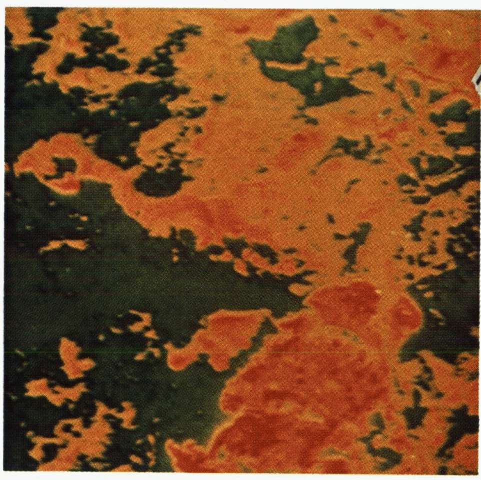
(B) ENHANCED SINGLE IMAGE (FRAME 6)
RED - OUTCROP, SLIDEROCK, AND COARSE MORAINE
GREEN - FINER SURFICIAL DEPOSITS, TIMBER, AND GRASSLAND



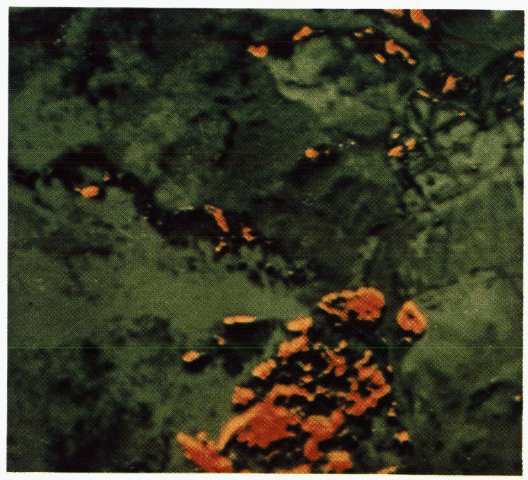
(C) ENHANCED COMBINED IMAGES (FRAMES 2 AND 7)
RED - OUTCROP, SLIDEROCK, AND COARSE MORAINE
GREEN - FINER SURFICIAL DEPOSITS TIMBER, AND GRASSLAND

Figure 4.5-7 Photograph and Enhanced Images of an Area in the Southern Part of the Gallatin Range (See Figures 4.5-4 and 4.5-5)

(A) PHOTOGRAPH FROM MULTIBAND 9-LENS CAMERA (FRAME 5)



(B) ENHANCED SINGLE IMAGE (FRAME 6)
RED AND ORANGE - HOT SPRING DEPOSITS (BOTTOM), LANDSLIDES (TOP), AND SOME CULTURAL FEATURES
GREEN - OTHER SURFICIAL DEPOSITS, TIMBER, AND GRASSLAND



(C) ENHANCED COMBINED IMAGES (FRAMES 2 AND 6)
RED - HOT SPRING DEPOSITS
GREEN - MOST SURFICIAL DEPOSITS AND ALL VEGETATION

Figure 4.5-8 Photograph and Enhanced Images of the Mammoth Area

The images used for the two-band experiments were color-separation negatives made from color and color infrared film, and multiband images from the ITEK 9-lens camera.

The following enhancement techniques were investigated using Yellowstone National Park imagery:

- Density slicing
- Enhancing different parts of the density curve
- Masking
- Redundancy test
- Edge enhancement
- Density matching
- Generalization of tones

4.1 Density Slicing

The 16-level quantizers, described in paragraph 3.1, can be adjusted so the relative widths of the 16-levels are different for each channel. This permits a wider range of enhancements than with one-band processing, and provides additive, as well as subtractive, manipulation. The effects of wide versus narrow spacing and position of the quantizer ramp can be examined rapidly by switching on first one quantizer and then the other and by exchanging the position of the two images.

4.2 Enhancing Different Parts of the Density Curve

The quantizer for one image can be shifted to enhance one part of the curve while the quantizer for the other image can be used to enhance some other part of the curve. Additional range can be provided by switching polarity.

4.3 Masking

One function of polarity switching is to provide positive negative masking. In this manner, all areas that have high reflectance in wavelength frame 2 and low reflectance in frame 7 can be enhanced by superimposing the positive transparency of frame 2 or the negative transparency of frame 7. Areas of high reflectance in frame 2 would not be enhanced, nor would those areas of high or intermediate reflectance in frame 7. (See figure 4.5-5.)

For example, bodies of gypsum can be detected by applying this masking technique. Weathered gypsum at the earth's surface has very high reflectance in the ultraviolet and very low emittance in the thermal infrared (Wolfe, 1969). By combining the ultraviolet positive (bright) and the thermal infrared negative (bright), areas underlain by gypsum should be reinforced and markedly enhanced in the resulting image.

4.4 Redundancy Test

Another function of masking is to test for redundancy of data. All nine images from a 9-lens multiband camera are not needed for any experiment. In fact, four probably is the maximum number. To determine whether, or how much, new information is contained in image 1 as compared to image 2, the red-green mix on each can be balanced to provide a neutral, that is, a yellowish-orange image of each. The polarity of one of the images is reversed to produce a superimposed positive of one on the negative of the other. If the screen is featureless, there is a complete redundancy of data. If any detail can be seen, it indicates one transparency contains information that the other does not. (See figure 4.5-4.) The high contrast obtained from widely separated spectral bands by this positive-negative masking technique, figure 4.5-4B, provides a means of edge enhancement.

4.5 Edge Enhancement

If the same procedure is used as just described for the redundancy test (paragraph 4.4) and the two transparencies are deliberately misaligned, the result is high contrast or edge enhancement along the adjacent area boundaries of different density or brightness. (See figure 4.5-5C.)

The advantages of this process over other techniques for edge enhancement are:

- Visual display versus computer printout
- Simultaneous production of several color zones
- Preservation of geometric image fidelity

4.6 Density Matching

One of the reasons for proportioning the signals for each of the transparencies to both the red and green video circuits is as follows. If the color is adjusted in such a way that the same density in each of the two transparencies is red, then when these two signals are combined they reinforce each other to produce a still brighter red on the video screen. In this way, it is evident that the same density value (reflectance) will occur in that given spot on the scene for both spectral bands. Wherever else red appears, that same density will occur on both transparencies. Other colors will indicate different densities. In a sense, this is a redundancy check, because wherever one particular color occurs (red, in this case), it indicates that the same information is contained in both transparencies.

5.0 SUMMARY

There is no direct evidence from the experiments described, but it is highly possible that this enhancement system can effectively map out subtle differences in reflective infrared photographs to show the location and extent of diseased or poisoned vegetation and to indicate whether the poisoning is due to geochemical

anomalies, changes in the water table, or other factors. In the present studies it was possible to delineate water-logged areas because of their effect on the vegetation. Also, deciduous forests could be clearly distinguished in most places from evergreen forests.

A display or "map", such as the one shown in figure 4.5-2B, clearly delineates bedrock exposures. This would prove to be an invaluable tool in such places as northern Maine and parts of Canada where a geologist might spend several days wandering around in the muskeg looking for an outcrop.

All forms of image enhancement have drawbacks. For instance, in the deliberate distortion of real image color and tone values, many of the values that identify familiar objects also become distorted (sometimes enhanced, sometimes suppressed) thus changing their interpretative significance.

With the possible exception of edge enhancement, nearly all methods of terrain study, by means of image enhancement, require that the interpreter already have considerable knowledge about the geology or terrain shown in the image. He must know what kind of material he wants to enhance and where some of that material is in the image. Prior knowledge is needed because of the literally infinite number of possible settings available in electronic enhancement systems.

The success of image enhancement data is directly related to the interpreter's knowledge of enhancement processes and his understanding of its problems and goals. For example, investigators interested in ocean depths have vastly different requirements and approaches than those interested in agriculture or geology.

6.0 CONCLUSIONS AND RECOMMENDATIONS

In many places bare rock can be distinctly separated from soil, grass, or forested areas. Although different kinds of rocks were not separated in these experiments, such separation is within the capability of the system.

In terms of reflectance, bare rock in place (bedrock) cannot always be distinguished on the basis of reflectance from bare rock (debris) that has moved as talus, slide-rock, or as large boulders in surficial debris, but in surface forms each is generally distinctive. Similarly, in areas largely covered by surficial deposits, the surface form is an important criterion for distinguishing between different genetic kinds or surface debris whose reflectance and, hence, image density, are indistinguishable. For these reasons, it is important to conduct part of the test using the straight video display rather than quantized or digitized video, in order to discern the surface form. After inspection of the straight video display, proper selection of position and widths of quantizing levels can be used effectively to enhance the appearance of the surface form or texture.

The most useful combination with multiband images proved to be the 9-lens system with blue or green color-separation images and frames 2, 3, and 9 of the reflective infrared. This confirms the results of the redundancy tests. An important advantage of the electronic image enhancement system is that the results of a wide variety and combination of enhancement experiments can be displayed and studied in real-time -- that is, the output is an immediate response to the input. The displays can be evaluated and adjusted promptly to achieve optimum enhancement. Other enhancement systems require a time lapse before the enhanced product can be viewed, because most of them can perform only one or a limited number of enhancement procedures.

The electronic image enhancement system has already proved to be effective in showing different depths of water bodies, and promises to be even more effective in the study of sedimentation and water pollution.

SECTION 4.6

OPEN-PIT MINING EVALUATION - IMAGE ENHANCEMENT
(TWIN BUTTES OPEN-PIT COPPER MINE)
Tucson, Arizona

William C. Henkes
United States
Department of the Interior
Bureau of Mines
1969

SECTION 4.6

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

3

1.0 INTRODUCTION

Experiments were made with a Philco-Ford color video enhancement system and micro-densitometers to obtain a sharper definition of the Twin Buttes open-pit copper mine features near Tucson, Arizona. The work was conducted by Mr. W. C. Henkes of the US Department of the Interior, Bureau of Mines, using color transparencies taken by the Gemini V and Apollo VI missions. (See figures 4.6-1 and 4.6-2.) The densitometers were provided by the Earth Resources and Mapping Sciences Division, Manned Spacecraft Center, NASA, Houston, Texas.

2.0 ENHANCEMENT SYSTEM

The electronic image enhancement system is capable of simultaneously scanning two transparencies and displaying combinations of processed and unprocessed signals from two spectral bands on a TV monitor. (See figure 3-1.) The information, displayed in color on a small television screen (viewing port), can then be photographed on color film (figure 3-2). The 16 slicing levels of the quantizers can be adjusted to provide enhancement of portions of the density range. Arbitrary colors can be assigned to the 16 density slices to make them more distinguishable. Controls are provided to vary the thickness of the density slices and perform masking operations.

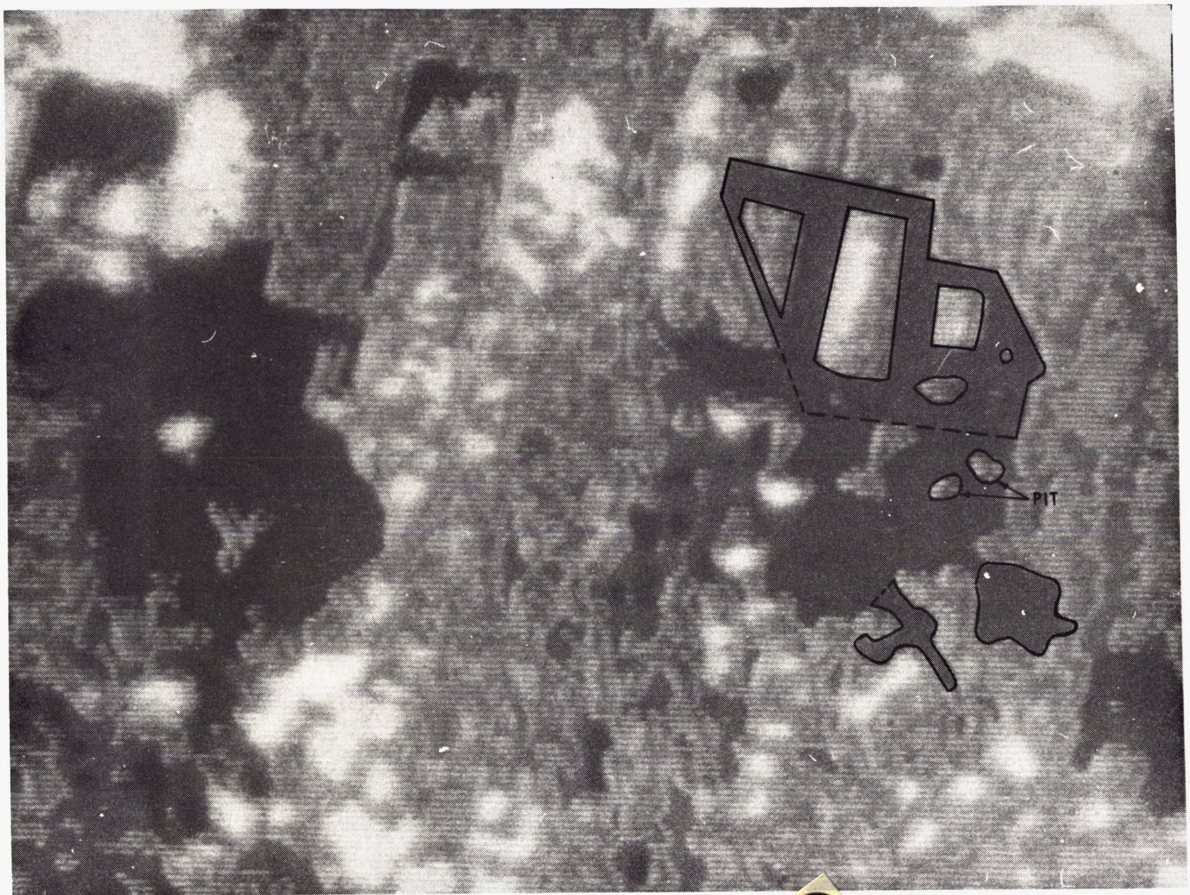
Several transparencies, using various filter combinations, were made from each of the Twin Buttes area space photographs. Using the electronic image enhancement system, numerous experiments were then performed with varying degrees of success.

3.0 RESULTS

It is apparent that the features of the mine are emphasized by electronic enhancement. However, it is doubtful that features not visible in the original will be discernable after enhancement. Enhanced imagery, suitable for aerial measurements, seems to be entirely dependent on the operator's experience with the system and prior knowledge of the area or object being examined.

GEMINI V-I-16, 21 AUGUST 1965

Figure 4.6-1 Twin Buttes Mine, Gemini V, Area of Dikes Only



4 APRIL 1968

SOLAR TIME:	0745
ALTITUDE:	135 STATUTE MILES
ORIGINAL SCALE:	1:2,867,000
SUN ANGLE:	±27°

Figure 4.6-2 Twin Buttes Mine, Apollo VI, Frame 1441

The density of the transparency varies gradually when going from the object across the object boundary into the background. As density slices move through these varying densities, the false or arbitrary color boundaries of the slices move laterally through the imagery. The net effect of this movement is an appreciable change in the aerial dimensions of the object being studied. An attempt at uniformity of enhanced image size was made by bringing the extension of the road between dams 2 and 3 to the threshold of disappearance.

The possibility of some form of automatic imagery analysis, using the electronic enhancement system, appears impractical because the enhanced image shows only those areas having the same density without identifying the areas. As an extreme example, the overall density of the Gemini V photograph shifted from left to right across the image, resulting in broad irregular bands generally having the same density.

A semi-automatic analysis may be possible using a combination of the electronic image enhancement system and the bureau's quantitative TV microscope (QTM). The standardization enhanced image could be displayed on a Bausch and Lomb photo data quantizer (PDQ) and the areas measured selectively with a light pen.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The experiments in image enhancement were inconclusive. Although certain features were made more apparent, it is questionable if the system can be adapted to automated interpretation. The micro-densitometer traces seem to offer possibilities if used in conjunction with the QTM or PDQ. More detailed experimentation needs to be done in this field. The QTM and PDQ systems indicate possibilities for semi-automated interpretation and change-detection.

SECTION 4.7

OBSERVATION OF FINER DETAIL IN COLD SPRING FLOW PATTERNS ACROSS MONO LAKE (Calif.) USING AN INFRARED IMAGE

Dr. J.P. Lyon
and
Mr. Keenan Lee
Stanford University
Stanford, California
1969

SECTION 4.7

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

A two-color video-display densitometer was found useful for the qualitative examination of temperature distribution patterns on infrared imagery. On positive imagery the film density is proportional to temperature, so any variation in density provides temperature information.

2.0 ENHANCEMENT SYSTEM

In many respects, the Philco-Ford electronic image enhancement system is similar to several commercially available densitometers, but its advantages are threefold:

- The width of the density slices is variable, as well as the total density range.
- Contrasting colors are more discernable than gray tones.
- The display is in real-time.

The versatility of the instrument combined with the real-time display enables the operator to selectively enhance any of the features he chooses. The advantage of the video display is that it does not require a facsimile printout in order to evaluate changes in control settings. However, a disadvantage is that a color photograph must be made of the video screen to obtain a permanent copy. This format problem, along with the relatively small original image size (70 mm by 70 mm), precluded the use of this instrument for the extraction of quantitive data.

One particularly useful application of the false-color densitometer was to trace water discharge patterns offshore from shoreline springs. On some infrared imagery of the northwest part of Mono Lake, figure 4.7-1, the patterns of spring water are rather complex because individual spring discharges coalesce with other spring water offshore, and the eye cannot distinguish between the subtle grey density changes. By projecting the imagery on the video screen and overprinting a single density slice, which is then varied, the discharge from any one spring can be made to move out from the shore and its actual flow path followed from the shoreline into the complex water patterns.

Figure 4.7-1 Temperature Distribution Patterns on Infrared Imagery

SECTION 4.8

AERIAL PHOTOGRAPHIC STUDIES OF THE COASTAL WATERS OF NEW YORK AND LONG ISLAND

Dr. Mahlon G. Kelly
Department of Environmental Science
University of Virginia
Charlottesville, Virginia
1970

SECTION 4.8

TABLE OF CONTENTS

1.0 INTRODUCTION

Aerial and satellite photographs show significant patterns of distribution of coastal bottom (benthic) vegetation and suspended materials in the water. A knowledge of these distributions, which are impossible to perceive from the surface, is obviously an important factor to understand coastal ecological processes and to aid in future planning. Benthic vegetation, as seen from the air, is a good indicator of environmental conditions in tropical clear-water areas. Work reported here is being extended to temperate turbid waters. Water color patterns caused by backscattered light from suspended materials are related to oceanographic conditions such as water mass boundaries, chlorophyll concentration, phytoplankton populations, suspended sediments, and the effect of man's sewage and dredging.

This study was initiated to find answers to the following questions:

- Many significant areas of benthic vegetation should be analyzed using aerial photography in temperate turbid waters. What types of benthic material may be seen? How do water conditions determine the type of photography that will be most useful?

- How do patterns of different water color, as seen in the photograph, relate to the distribution of different water masses and their properties?

- How do the basic physical and chemical properties of the water, as well as the phytoplankton populations and distribution of suspended particulates, relate to the distribution of coastal water bodies?

- How do these properties and materials relate to their appearance in the photograph?

Typical areas of bottom material were studied using the bottom biota, and by using the methods described by Kelly (1969). Other areas were examined and field observations extended using hand-held photography and visual observation from light aircraft. Various color films and broad-band multispeed photography were used to determine the best techniques for photography of the benthic material.

Water color studies were made by sampling the water and analyzing its characteristics concurrent with the photographic flights. Various image tone-enhancement techniques were compared and applied to the photography to bring out very low contrast images of water color for qualitative interpretation and provide quantitative information for comparison of the field measurements with the photographic images. A typical turbid water interface was selected off Montauk Point. It was repeatedly sampled and studied in conjunction with observations from light aircraft. Preliminary analysis of this data indicates that differences in water masses are visible, but the situation is very complex.

2.0 PHOTOENHANCEMENT

2.1 Introduction

Color photoenhancements were produced of selected areas to compare different methods of quantifying and interpreting images of backscattered light from different bodies of water. Although the enhancements were made of several areas, Jamaica Bay was studied using all the methods, because it had the greatest variety of conditions located in one area and provided the best field data.

Variations in water colors and saturation are usually gradual and have a limited tonal range. Image contrasts are low, edges indistinct, and it is very difficult to compare image densities of separated points with a single frame. Very slight differences in image tone may be visible, but are difficult to detect objectively. Other differences may be present, but require extreme contrast enhancement to be visible at all. Therefore, image contrast analysis is very useful for qualitative photo-interpretation.

Since the suspended particulates are responsible for the backscattered light from water, it was hoped that a quantitative relationship might be found between image density and the characteristics of water masses. Quantitative image enhancement should therefore be a useful tool for comparing different water masses in terms of their physical properties, suspended material, and phytoplankton populations. Even if a quantitative relationship cannot be found between the amount of suspended material and the image density, it should be possible to use the image density to characterize water bodies. In this way image contrast analysis might be useful for mapping the distribution of water masses.

Six methods of image contrast enhancement were used: three video methods (both digital tonal separation or "slicing" and bispectral "mixing"), photographic density slicing, scanning imaging microdensitometry, and high-contrast color separation.

2.2 Video Enhancement

The same basic principle was employed by the two methods studied, that is, the conversion of image densities into electrical impulses using either a vidicon camera or an imaging optical line scanner. Both methods provide a digital analysis of the electrical impulses and a video display of an enhancement that represents different image densities as zones of different colors. The video enhancements do not reproduce successfully in halftone. Therefore, illustrations are not to be included in this report.

Both methods produced spectacular images that could be manipulated by the interpreter. Philco-Ford equipment could not be used for quantitative comparison of image densities because of fall-off in intensity of the optical input away from the center of the image. Although there was considerable loss in resolution, it was adequate for present use. The magnification and field of view were determined by the transparencies. The equipment was most useful for the interpretation of patterns. The patterns were sharply defined and could be related to the surrounding features that influenced the transport of the water. For example, transport, diffusion and mixing of sewage effluent could be very effectively seen, at least qualitatively. This system provided great flexibility in the selection of width and

distribution of image density slices and was perhaps the best of the methods tested for qualitative interpretation. If the edge fall-off effect, magnification, and field of view could be improved, the Philco-Ford equipment would have been useful for quantitative work as well.

Conditions for the appraisal of Spectral Data Systems (SDS) equipment were not optimal since the only color transparencies available were photographed at 60, 000 feet. Examination of the equipment was cursory because of its limited availability. Although optical systems were available to improve resolution, it had lower resolution than the Philco-Ford equipment. It had advantages in that the field could be selected by the operator and there was no edge fall-off. This means that the output can be calibrated using a density wedge and portions of the image can be quantitatively compared. In other words, this equipment can be used for both qualitative photo-interpretation and image density analysis. It had the disadvantage that the width of individual density slices could not be selected. Further usage would be necessary to fully evaluate this equipment. If used with color separations, the SDS and Philco-Ford equipment should be a good compromise between the high spatial and density resolution of the photographic and mechanical scanner methods and the need for control and manipulation by the photo-interpreter. The real-time control of these methods provided the best advantage over other equipment.

The Philco-Ford video equipment can be operated in an analog as well as the digital mode described in paragraph 2.1. Color separation internegatives were inserted into two separate channels and the spot-scanner output was viewed on the video screen as a normal negative of varying brightness and contrast. This provides manipulation of contrast for each internegative, and since one channel produces a red image and the other a blue, varying degrees of mixing in false two-color rendition can be produced. This is useful for qualitative enhancement of image contrast, especially since it can be controlled by the interpreter, even through color differences in the original photography are insufficient for useful false-color rendition by recombination. Masking effects can also be produced and are helpful for delineation of boundaries. This method, of course, will not produce quantitative results, but it is intended as a photo-interpretive tool. This equipment is useful for qualitative interpretation using variable contrast and

masking that can be controlled by the interpreter, but is not useful for false-color rendition because of a lack of color contrast in the original images.

3.0 SUMMARY

- Digitized and analog video, photographic, and optical-mechanical contrast enhancement techniques were applied to the photography to provide objective interpretation of the patterns of backscattered light.

- All methods provide good qualitative interpretation of shape and boundaries of the patterns. The analog and digital video methods had the advantage of control by the photo-interpreter.

- The photographic and line-scanning techniques provided quantitative specification of image density patterns for comparison of widely separated areas.

- The line-scanning method has the advantage of providing both quantitative interpretation and limited operator control.

- The photographic and line-scanning techniques make it possible to see density differences not visible in the original material. This may be of particular importance in analysis of less turbid waters.

- Particle backscatter should not be confused with bottom reflectance, as may have been done in other work.

- Quantitative enhancement techniques should have the greatest use in providing quantitative study of the distribution of water quality parameters.

SECTION 5

SUMMARY AND CONCLUSIONS

The FRSL optical color combiner has the best resolution. (See figure 4.1-3 of the report by Mr. J. D. Lent, University of California, Berkeley, in section 4.1.) However, the Philco-Ford console viewer has a finer resolving scanner and consequently ranked second in resolution characteristics. The IDECS electronic color display and analysis system showed the poorest resolution and ranked third. It should be noted that all three enhancement systems had advantages and limitations.

In section 4.2, page 4.2-11 of the report by Dr. J. E. Estes, it was found that Philco-Ford electronic combiner imagery ranked fourth for accuracy when compared with the following image types:

Rank	Imagery
1	Panchromatic film with a Wratten 58 filter
2	Panchromatic film with a Wratten 25A filter
	FRSL optical combiner image
	Infrared Ektachrome film and Wratten 15 filter used with the IDECS electronic combiner
	Infrared Ektachrome film with a Wratten 15 filter
	University of Kansas electronic combiner image
3	Black-and-white infrared film with a Wratten 89B filter.
4	Philco-Ford electronic combiner image.

While the use of electronic enhancement equipment shows promise in facilitating the interpretation of earth orbital photography, it was generally agreed that more research must be carried out to determine if electronic enhancement equipment can give results comparable to those that can be obtained using multiband optical enhancements.

In the studies conducted by Dr. Teas of the University of Miami, it was noted that the use of an electronic image enhancement system proved very useful in the identification of vegetation in the Florida keys. The US Geological Survey's study of Yellowstone National Park pointed out the usefulness of the viewer in the identification of bare rock, soil, grass, forested areas, etc.

Although the Philco-Ford electronic image enhancement system was not particularly helpful in the identification of boundaries at the Twin Buttes mine, as indicated in the study by Mr. W. C. Henkes, it was of considerable help in the study of water patterns and the distribution of water quality parameters on Mono Lake, California, as described in the study by Dr. J. P. Lyon and Mr. K. Lee.

While it is apparent that color enhancement techniques are generally in the early stages of development, their potential benefits warrant the effort to improve and quantify these techniques to provide predictable and consistent results from future experiments. The success of enhancement techniques is directly related to the interpreter's understanding of the problems and goals and his knowledge of enhancement processes. It would be desirable if the electronic image enhancement viewer could be operated by individuals without prior knowledge of geology, biology, or the terrain as shown in the image. However, due to the wide range of possible enhancement capabilities, a lack of specific knowledge limits the use of this equipment.

In most applications discussed in this report, the use of electronic video enhancement viewers proved helpful, but it was generally agreed that further research and tests are needed to determine the validity of using electronic video enhancement techniques in preference to aerial or spatial photo-optical techniques.

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

User	Date of Equipment Usage
University of California Department of Geography Forestry Remote Sensing Laboratory (FRSL) Berkeley, California Mr. J. D. Lent	14 May 1969
University of California Santa Barbara, California Dr. J. E. Estes and University of Kansas Lawrence, Kansas Dr. D. S. Simonette Mr. G. W. Dalke	24 May 1969 21 June 1969
University of California Department of Geography Forestry Remote Sensing Laboratory (FRSL) Berkeley, California Dr. R. N. Colwell Mr. R. Thaman Mr. L. Senger Mr. R. Thorley	2-6 June 1969 21 June 1969 16-17 July 1969 1-17 August 1969
University of Miami Coral Gables, Florida Dr. H. J. Teas	28 October to 2 November 1969 17-23 February 1970
U.S. Department of the Interior Geological Survey Mr. H. W. Smedes Mr. E. Ruple Mr. D. Tatlock Mr. G. Greene	28 April to 5 May 1969
U.S. Department of the Interior Bureau of Mines Mr. W. C. Henkes	28 July to 1 August 1969

User	Date of Equipment Usage
Stanford University Stanford, California Dr. J. P. Lyon Mr. K. Lee	1-3 July 1969
Univeristy of Virginia Department of Environmental Science Charlottesville, Virginia Dr. M. G. Kelly	12-16 June 1970